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Used Batteries and the Environment: A Study on the Feasibility of Their Recovery

Report EPS 4/CE/1
May 1991

Canada

Environment Canada Environnement Canada

91-04398/

ENVIRONMENTAL PROTECTION SERIES

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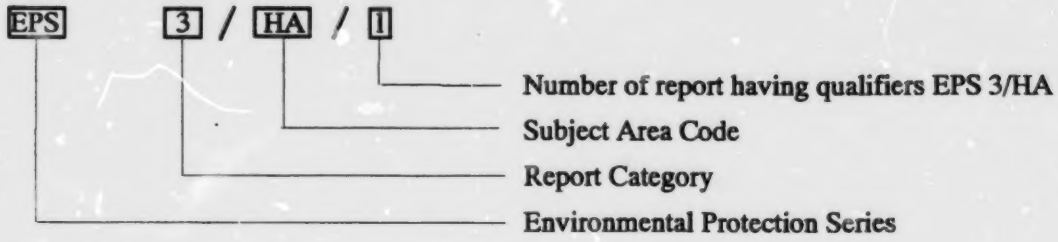

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Used Batteries and the Environment: A Study on the Feasibility of Their Recovery

by

Eutrotech Inc.
Saint-Robert (Quebec)

for the

Technology Development Branch
Environmental Protection
Conservation and Protection
Environment Canada

Report EPS 4/CE/1
May 1991

CANADIAN CATALOGUING IN PUBLICATION DATA

Eutrotech Inc.

Used batteries and the environment : a study on the feasibility of their recovery

(Report ; EPS 4/CE/1)
Issued also in French under title: Les piles usées et l'environnement.
Includes an abstract in French.
Includes bibliographical references.
ISBN 0-662-18677-X
DSS cat. no. En49-25/4-1E

1. Battery industry -- Canada -- Environmental aspects. 2. Storage batteries -- Recycling. 3. Mercury -- Waste disposal. I. Canada. Environment Canada. II. Canada. Technology Development and Technical Services Branch. III. Series: Report (Canada. Environment Canada) ; EPS 4/CE/1.

TD196.M385413 363.72'88 C91-098635-5

©Minister of Supply and Services Canada 1991
Cat. No. En 49-25/4-1E
ISBN 0-662-18677-X

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Abstract

Used batteries are a significant source of heavy metals (especially mercury), and when they are discarded, this waste is dumped into the environment. On the average, alkaline batteries contain 100 times more mercury than traditional carbon-zinc batteries. The massive increase in the sales of alkaline batteries has directly affected the quantity of mercury released into the environment.

Canadian consumption of new batteries accounts for the annual release of about 50 tonnes of mercury into the environment. This represents 35% of the mercury released by human activities in Canada, a figure that exceeds the emissions produced by industrial sectors. Studies done in Europe, the United States, and Japan, indicate that a battery recovery program would be a difficult undertaking, and would not be very effective. However, it is possible to reduce 80% of mercury emissions from used batteries, by:

- *replacing mercury oxide batteries with those containing little or no mercury (this is both technically and economically feasible);*
- *adopting legislative measures, similar to those in the European Economic Community, which aim to reduce the mercury levels in alkaline batteries by 85%; and*
- *installing wet gas scrubbing equipment in municipal incinerators; since mercury, emitted as a gas, is not retained by the fly-ash removal systems currently used.*

Résumé

L'élimination des piles usées constitue une source importante de rejets de métaux lourds, tout particulièrement de mercure, dans l'environnement. L'accroissement important des ventes de piles alcalines, qui contiennent en moyenne 100 fois plus de mercure que les piles charbon-zinc traditionnelles, a eu un effet marqué sur les quantités de mercure rejetées dans l'environnement.

Selon les informations recueillies, la consommation canadienne de piles neuves représenterait un rejet annuel d'environ 50 tonnes de mercure dans l'environnement, soit 35% de l'ensemble des sources anthropogéniques de mercure au Canada, devançant ainsi largement les émissions provenant des secteurs industriels. Compte tenu des expériences entreprises dans plusieurs pays européens, aux États-Unis et au Japon, la réalisation d'un programme de récupération des piles usées serait difficile et probablement peu efficace. Par contre, il serait possible de réduire d'environ 80% les émissions de mercure imputables aux piles usées en:

- *encourageant la substitution des piles à l'oxyde de mercure par des piles contenant peu ou pas de mercure, ce qui est actuellement techniquement et économiquement réalisable;*

- *adoptant des mesures incitatives et/ou législatives similaires à celles de la Communauté économique européenne qui visent à réduire de 85% la concentration de mercure dans les piles alcalines;*

- *installant des équipements de lavage des gaz de combustion sur les incinérateurs municipaux, le mercure sous forme gazeuse n'étant pas retenu par les systèmes de dépoussiérage.*

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Acknowledgements

The authors, Mrs. Martine Ménard and Mr. Christian Chevalier would particularly like to thank the following people for their generous cooperation:

- Mr. Gérald Girouard, Environment Canada
- Mrs. Miriam Bieri, Aktion Saubere Schweiz, Switzerland
- Mrs. Christina Jacob, Greater Vancouver Regional District
- Mr. Jean-Louis Chamard, Environnement Québec, Récupération et Recyclage

We would also like to express thanks to those who sent us information by mail.

The help of various people and organizations in the countries we visited during our technical mission in Europe is also greatly appreciated. A list of our main correspondents in other countries is shown in the Appendix.

Summary and Conclusions

Human activities have considerable effect on the quantity of mercury in circulation in the biosphere, and the toxic effects of mercury are well known. The last few decades have seen a progressive reduction, indeed, elimination of the use of mercury in several domains.

During this same period, the quantity of mercury used by industry in electric batteries has rapidly increased due to the popularity of portable appliances and to the marketing of alkaline batteries. Note that the primary cells currently used (alkaline, carbon-zinc, mercury oxide, silver oxide and zinc-air) contain variable quantities of mercury, generally used as an inhibitor in the zinc anode, or as the cathode in the case of mercury oxide batteries.

Alkaline and carbon-zinc batteries comprise the largest share of the market by weight and number of batteries sold. The phenomenal growth of the alkaline battery market to the detriment of conventional batteries (carbon-zinc) has a marked effect on the increase in the quantities of mercury used; alkaline batteries contain approximately 100 times more mercury than conventional batteries.

After rapid expansion, the button battery market is beginning to stabilize. Mercury oxide batteries are being replaced by silver oxide batteries, lithium batteries, and in the case of auditory prosthesis, zinc-air batteries.

Discharged batteries represent an important part of the heavy metals contained in household refuse. Mercury contained in electric batteries that are not recycled, finds its way into the environment. The extent of damage depends on the method of disposal. Considering the high volatility of mercury, the incineration of household refuse constitutes a threat to the environment, if the combustion gases are treated in the conventional manner (filtration).

In many countries, increased public awareness of mercury in the environment has led to the implementation of programs aimed at recovering all products containing mercury, even those products with small quantities of mercury such as primary cells and thermometers. Today, the collection and recycling of environmentally dangerous products occurs in several European countries, and in Japan.

The first collection and recycling programs for mercury button batteries started around 1975. Certain countries have expanded their collection programs to include cylindrical batteries and in certain cases, rechargeable batteries (nickel-cadmium batteries). As programs expand to include a wider range of battery types, appropriate treatment or disposal becomes more complex and expensive. In many cases, local government and the battery industry cooperate so that the collection and treatment of used batteries is more efficient. The collection and management of used button batteries poses unanswered technical and economic problems, and until these are resolved, collection and treatment programs will be restricted in scope.

The experiences of other countries show that there are problems related to the sorting, transportation, storage and final treatment of discharged batteries. The recent closing of a mercury treatment installation in Western Germany has temporarily compromised the treatment of mercury oxide button batteries in several European countries. For other types of batteries, pilot treatment installations are the object of research and development in The Netherlands, Switzerland, and Japan.

Following directives issued by the European Economic Community (EEC) advocating an 85% reduction in the quantity of mercury

contained in alkaline batteries by 1990, many member countries took legislative action to encourage the battery importers and manufacturers to reduce reliance on mercury. For instance, certain countries strongly encourage the use of zinc-air batteries instead of mercury batteries in auditory prosthesis. Such initiatives have considerably reduced battery-related mercury emissions.

The problem of treating used nickel-cadmium rechargeable batteries manufactured for domestic use is relatively new. These batteries are often collected with other types of batteries and must be separated from them before treatment.

Estimates from this study reveal that the annual Canadian consumption of primary batteries is approximately 48 tonnes of mercury. This represents about 35% of the total mercury used in Canada.

Mercury batteries are the source of only seven tonnes of mercury per year, thus, a collection program for mercury batteries alone would not significantly reduce the emissions of mercury from discharged batteries. It should also be noted that applications for this type of battery are becoming increasingly rare since alternative battery types are available that are profitable and require less mercury.

Many American and Canadian environmental associations are showing an increasing interest in the presence of discharged batteries in household refuse. As a result, certain American and Canadian cities have recently initiated programs for the collection of discharged batteries.

In Canada, a collection and treatment program will be more difficult to implement, because of distances between urban centres and the resulting increase in transportation costs.

This study concludes that it is possible to considerably reduce the emissions of mercury from discharged batteries in a way that is more effective and economical than a program of collection and treatment.

In Canada, it would be possible to attain a near 80% reduction of mercury from used batteries by applying the following recommendations:

- Encourage the substitution of batteries containing little or no mercury for mercury oxide batteries. This is both technically and economically feasible. For example, the zinc-air batteries can replace the mercury batteries in auditory prosthesis.

- Adopt legislative measures similar to those of the EEC which aim to progressively reduce the concentration of mercury in alkaline batteries until it is 15% of the present concentration.

- Equip municipal incinerators with wet gas scrubbers. The gaseous mercury emitted during the combustion of household refuse easily bypasses the systems of fly-ash removal generally used.

Section 1

Introduction

The general public is becoming increasingly concerned with the issue of heavy metal contamination of the environment. For several years, many industrialized countries have been dealing with the disposal problem of used batteries containing mercury. Canada, though a large consumer of batteries, lacks information on this subject; therefore, it is essential that this situation be evaluated.

In Canada, research has been carried out for many years into problems caused by processes (particularly industrial processes) that dump heavy metals into the environment. Implementing measures to reduce the emission of toxic substances into the environment is a priority of the Canadian government.

This study is an overall evaluation of the disposal of used batteries in Canada, and provides some general guidelines for measures to minimize the associated environmental impacts. The toxicity of mercury has already been reported extensively in other studies and it is only discussed briefly here. However, estimates of the amount of mercury entering the Canadian environment are made, and data is provided that will allow federal authorities to decide if it is necessary to adopt measures to reduce mercury emissions from the disposal of used batteries.

The primary purpose of this study is to evaluate the feasibility of implementing a program for the collection and recovery of used batteries in Canada, while taking into account profitability. Reviewing the experiences of countries that have battery disposal programs was particularly valuable for this study. The authors corresponded with various foreign government departments or agencies (listed in the Appendix) that are involved with battery recovery programs, and during a technical mission (Switzerland, The Netherlands, and France) in September 1987, interviews were carried out with those responsible for collection programs; as well, several battery recovery installations were visited.

Section 2

Mercury and the Environment

2.1 General Information

Mercury has been known since ancient times. It is a metallic element with a lustrous silvery-white colour. Its chemical symbol, Hg, is an abbreviation for "hydrargyrum", which means liquid silver in Latin. It is the only metal that is liquid under normal conditions. Its specific gravity is 13.55 g/cm^3, its melting point is -39°C, and its boiling point is 357°C. Mercury does not oxidize at regular temperatures; however, when it is brought close to its boiling point, it absorbs oxygen and converts into a red, crystalline powder, or mercury oxide (HgO), which is mainly used as a pigment in paints, and as an electrode in batteries.

Mercury has a very low viscosity and a high surface tension, which give it strange mechanical properties. This element flows easily without clinging to a surface, and breaks up into tiny droplets as the result of the smallest jolt.

The main source of mercury is mercury sulphide or cinnabar (HgS). The most concentrated ores contain about 7% mercury. On average, Italian ores contain 1.1% mercury, while American ores contain only about 0.5%, or 500 ppm. Notable concentrations of mercury are also found with other metal sulphides. The exploitation of lead, copper, and particularly zinc ores generates a significant amount of atmospheric emissions of mercury. For example, the mercury content of zinc concentrates in the Val d'Or region is 150 ppm[1]. Occasionally, the concentrations of mercury associated with zinc ores are high enough that the mercury can be exploited while extracting the zinc.

The various organic or inorganic mercury compounds in current use are all volatile, and most decompose into mercury fumes[1].

2.2 Uses of Mercury

Mercury is one of the seven metals known since ancient times. Red cinnabar has long been used as a dye; pigments containing mercury were discovered in a Syrian tomb dated 2 000 years before Christ[2]. In fact, mercury may have been extracted from the famous mine in Almadén (now known as Sisapo) Spain, four centuries before the birth of Christ.

The bacteriostatic characteristic of mercury was known to the Romans, who used cinnabar as make-up, two centuries before the birth of Christ.

Because of high toxicity, bioaccumulation and persistence in the environment, mercury compounds are extremely dangerous. Over the last four decades, wide use in agriculture and industry has led to numerous environmental disasters, prompting government authorities to adopt legislative measures to reduce emissions into the environment, and to encourage efforts to find substitutes for mercury-based products. Nevertheless, mercury is still used today; the most important applications are listed in Table 1.

In the battery industry, the amount of mercury used has increased significantly. In the United States, over 50% of all the mercury consumed - 1 000 t/yr - is used in the manufacture of electric batteries[3,4]. Apart from the battery industry, the quantity of mercury used in most other applications has decreased, or remained relatively stable since 1970.

Table 1 Some Uses of Mercury*

Dentistry
- dental amalgam
Agriculture
- mercury (II) chloride
- mercury (I) chloride
- phenylmercuric acetate
- phenylmercuric lactate
- phenylmercuric oleate
Pharmacology
- merbromin (mercurochrome)
- mercury (II) chloride ammoniated
- yellow mercuric oxide
- blue ointment (mercury)
- nitromersol
- merthiolate (thimerosal)
- mercaptomerin (thiomerin)
- chlormerodrin
Electrical equipment
- current rectifiers
- switches
- fluorescent tubes
- mercury vapour lamps
Instrumentation
- thermometers
- pressure gauges
- other
Caustic Soda Industry
Gold Recovery
Paint Manufacturing
Battery industry
- carbon-zinc batteries
- alkaline batteries
- mercury oxide batteries
- silver oxide batteries
- zinc-air batteries

Source: 1

* The list is not exhaustive

2.3 Sources of Mercury Emissions into the Environment

2.3.1 Natural Sources

Most of the mercury in the environment comes from natural sources, such as:

- gases released from the earth's crust;
- erosion;
- volcanic flow; and
- oceanic evaporation.

Gases released from the earth's crust are by far the greatest source of mercury. Estimates for the amount of mercury emitted naturally into the biosphere vary widely. According to various authors, global figures range between 5 000 to 150 000 t/yr. However, since the beginning of the industrial age, human activities have affected the natural mercury emission mechanisms. These modifications are the result of:

the acceleration of erosion processes;

deforestation and desertification; and

the excavation and transportation of surface materials during large-scale civil engineering works (roads, dams, etc.).

Moreover, recent studies have shown that acid rain accelerates the release of metals from rock into the environment. Even though there has always been a certain amount of mercury present, careful attention should be paid to localized human emissions that cause mercury to become concentrated enough to pose serious health problems.

2.3.2 Man-Made Sources

Despite the importance of natural emissions, at present, human activities related to industrial development play a prominent role in the amounts of mercury in circulation in the biosphere. Studies on the mercury content of arctic and antarctic ice have revealed that these human activities have resulted in an increase in the concentrations of mercury compounds in the environment[5]. In fact, Weiss *et al.* (1971) have shown that Greenland ice layers corresponding to 800 years before the birth of Christ contain 60 ng/kg of mercury. Samples dated at 1815 and 1946 also show an average concentration of 60 ng/kg of mercury. On the other hand, samples corresponding to the period between 1952 and 1965 had mercury concentrations that were twice as high, with an average of 125 ng/kg.

This spectacular increase can be attributed to human activities, such as:

- the alteration of the earth's crust;
- the exploitation of mines;
- the use of fossil fuels;
- industrial processes; and
- the use and disposal of compounds containing mercury.

2.4 Toxicity of Mercury

For centuries, mercury has been highly valued for its unique characteristics (especially for its very effective medicinal properties). For a equally long time, people have been aware of the toxicity of this element and its compounds. Poisoning from metallic mercury is well documented; poisoning was widespread among the miners who worked the Almadén mines, in Spain. In the 16th century, Paracelsus described the symptoms of mercury poisoning in miners and foundry workers, and he made many recommendations concerning the therapeutic uses of mercury compounds[6].

Mercury is not a "vital" element; that is, it is not used by any living organism to ensure its vital functions. In fact, its highly toxic properties have been thoroughly documented.

The worst environmental disasters have taken place in Japan and Iraq (Table 2). These events led to an increased awareness on the part of government authorities in various industrialized countries.

The numerous mercury compounds possess varying toxicity levels. The most toxic are the organic compounds: methyl mercury is one of these.

In its organic form, mercury has three degrees of oxidation depending upon whether it is present as elementary metallic mercury (Hg), mercury (I) salt (Hg_2^+) or mercury (II) salt

Table 2 Main Cases of Methyl Mercury Poisoning

Country	Year	People Affected	Deaths	Sources of Mercury	Cause
Japan (Minamata)	1953-1959	800	111	industrial waste	methyl mercury in fish
Japan (Niigata)	1964	500	4	industrial waste	methyl mercury in fish
Iraq	1972	6 530	459	seed disinfectant	eating cereal grains contaminated with methyl mercury

Sources: 6 and 7

(Hg^{++}). Since mercury is very volatile, it can emit heavy concentrations of fumes that can affect the central nervous system. Exposure to mercury (II) salts (Hg^{++}) may damage the kidneys and produce nephrotic syndromes. Metallic mercury is transformed by the organism into an ion (Hg^{++}); damage to the kidneys may also be caused by inhalation of mercury fumes[6].

The organic compounds are chemically characterized in a covalent bond between the mercury and a carbon atom. Inorganic mercury may be transferred into the organic form through a bacterial process called methylation.

The rate of methylation in soils or sediments depends upon[8]:

- **The amount of microbial activity** - mercury methylation is directly related to microbial activity in soils and aquatic sediments;
- **The oxygen concentration** - aerobic conditions facilitate the transformation of mercury (II) salts (Hg^{++}) into methyl mercury; nevertheless, the anaerobic methylation of metallic mercury is also possible;
- **The pH and temperature levels** - any factor that affects microbial activity will affect mercury methylation; a change in pH may also change the type of mercury compound produced; dimethyl mercury is more likely to form under neutral or alkaline pH conditions, and (mono) methyl mercury under low pH conditions; and
- **The presence of sulphides** - given the affinity of mercury for sulphur, the presence of sulphides reduces the rate of methylation; this is probably due to the very low solubility of mercury sulphide (HgS).

Dimethyl mercury, which is more volatile and less soluble in water, eventually spreads by evaporation into the atmosphere; while methyl mercury is controlled by microbial activity and passes through the food chain[9]. Bioaccumulation factors in the order of 3 00 to 27 000 have been reported[8]. This means that mercury concentrations in fish flesh may be 10 000 to 25 000 times higher than the concentrations of mercury in their surrounding aquatic environment (water and plankton). Even though the consumption of contaminated fish is the usual cause of poisoning in people, the consumption of

fish-eating mammals and birds also represents a real threat, particularly for native populations. The pathological process in people can be simply described: when contaminated fish or other foods are consumed, the mercury ingested in organic form is transformed into methyl mercury chloride under the activity of the gastric acids. This organic mercury compound then passes into the blood stream, and is carried to the central nervous system and the brain.

The chemical symptoms of methyl mercury poisoning (hydrogyrism) are:

- loss of sight and hearing;
- intellectual degeneration;
- progressive loss of movement coordination;
- numbness and tremors in the limbs; and
- congenital disorders[9].

Section 3

Primary and Secondary Cells

The first electric cell was invented in 1800 by an Italian, Alessandro Volta. It was cylindrical in shape and consisted of a series of copper and zinc discs insulated from each other by cloth or cardboard washers immersed in acidified water. A metal wire connecting the first and the last zinc discs carried an electric current. The growing use of the telegraph after 1830 led to the development of electrochemical cells. In 1870, a Frenchman, Georges Leclanché, invented the traditional carbon-zinc dry battery that wasn't industrially produced until after the 1900s.[10] This source of energy opened unimaginable possibilities, by allowing the users to become independent of power supply networks.

The flashlight was introduced at the turn of the century, about 20 years after Edison's invention of the incandescent bulb. In the United States alone, the annual production of batteries amounted to two million units. Since that time, the market for commercial batteries has undergone two periods of rapid growth: in the 1920s, with the introduction of the domestic radio; and more recently with the widespread use of portable miniaturized electrical equipment.

During the last few decades, the battery industry has enjoyed phenomenal growth. At present, its worldwide sales amount to several billion dollars. In the United States alone, the battery market is 20 times larger than that of toothpaste or films.[11] Over 95% of the battery manufacturing activity in the United States is based on the production of four types of secondary cells and nine types of primary cells.[12]

3.1 Background

By definition, a "cell" is a system or device that converts chemical energy into electrical energy. Generally, the term "battery" defines an assembly of cells arranged in series or in parallel, to provide the desired voltage. In practice, users do not make a clear distinction between the terms "cell" and "battery". Consequently, they are often used interchangeably.

All the cells that are available on the market operate in accordance with the same principle; namely, that energy developed during an oxidation-reduction chemical reaction is directly transformed into electrical energy. The chemical reaction is produced by two electrodes immersed in a liquid or solid electrolyte[13]. During this operation, the cathode (positive electrode) is reduced by the absorption of electrons released by the oxidation of the anode (negative electrode). As they are displaced from the anode, the electrons are forced to use an external circuit (for example, the filament of a flashlight), where they release energy.[10]

It is important to note that the reaction of the primary cells takes place only in one direction: it is irreversible and ends when all the chemical energy of the system has been consumed. In the case of secondary cells, the reaction is reversible; these cells can be recharged by supplying an external source of energy.

Batteries come in various shapes and sizes; generally they are cylindrical, rectangular, or button-shaped (Figure 1). Button batteries are also cylindrical in shape, but their height is smaller than their diameter. The specifications of the International Energy Commission[14] provide for a general classification of battery systems by group. Alkaline, manganese, carbon-zinc, and rechargeable nickel-cadmium batteries are usually cylindrical in shape.

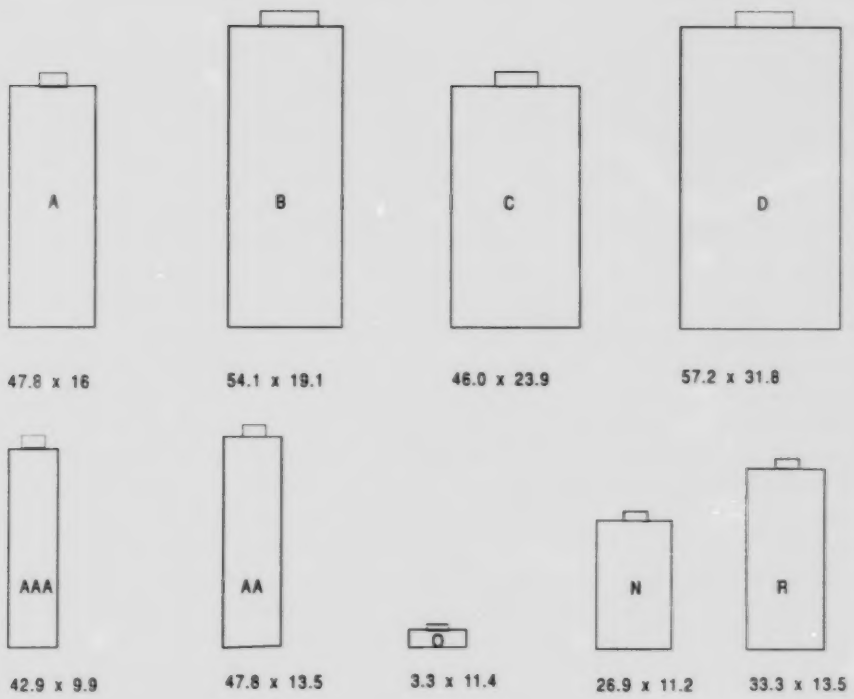


Figure 1 Battery Shapes and Sizes[16]

The most widely used variety is the "AA" format. The 9V battery, which consists of an assembly of six, 1.5 V batteries connected in series, is rectangular in shape, and both terminal contacts are on the same end.[15]

3.2 Energy Characteristics of Primary Cells

The total available energy of the cell (Figure 2) is a measurement of the quantity of electricity that can be released (in Wh). For the same system, it is directly related to the size of the batteries. For example, the smallest button battery has an energy of 100 mWh. The size "D" cylindrical battery has an energy of about 2 to 15 Wh. Rechargeable batteries used in tools have an energy of 20 to 100 Wh.[16]

The energy obtained from batteries is much more expensive than the electricity provided by the domestic power supply network. They provide about 50 times less energy than the amount required to make them. The kilowatt-hour provided by a carbon-zinc or alkaline battery is about a thousand times more expensive than the kilowatt hour obtained from a wall outlet; the kilowatt hour provided by a button battery is about 100 000 times more expensive.[10]

The voltage of a battery represents the difference in potential between the cathode and the anode, and it is rarely above 2 V (Table 3). The "AAA", "AA", "C", and "D" formats generally produce 1.5 V. In most cases, the manufacturers use the same chemical formula for all their formats, so it follows that the largest batteries are the most powerful. Thus, "C" batteries provide twice as much energy as "AA" batteries; and "D" batteries provide twice as much as "C" batteries. Note that the voltage of lithium

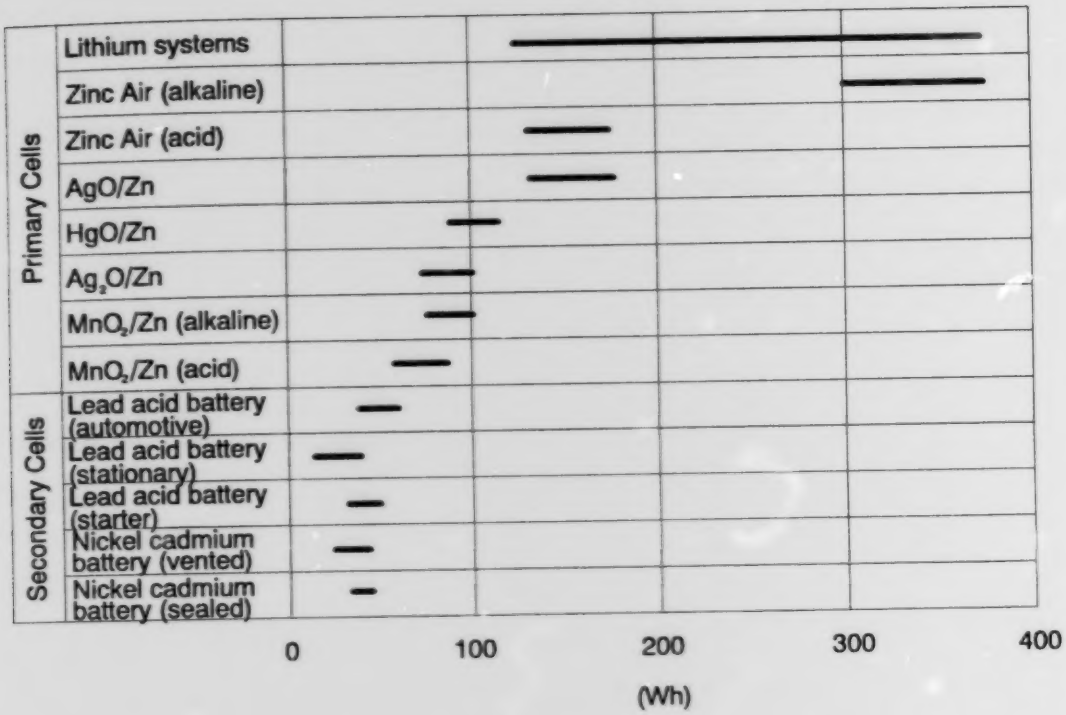


Figure 2 **Energy Densities of Various Batteries[18]**

Table 3 **Voltage of Electric Batteries**

Type of battery	Voltage (V)
Carbon-zinc	1.5
Alkaline	1.5
Mercury oxide	1.35
Silver oxide	1.5
Zinc-air	1.45
Lithium	1.5-3.9
Nickel-cadmium	1.2

Sources: 17, 19 and 20

batteries is twice as high as that of the other systems.[17]

All primary cells start to discharge slowly as soon as they have been made. The off-load lifetime of batteries is the time during which they preserve a minimum energy reserve while not in use. This period of time is also known as "shelf life". Carbon-zinc batteries lose moderate amounts of power when they remain too long on the dealer's shelves.[15] On the other hand, alkaline batteries offer excellent characteristics in this respect; they lose only between 2% and 5% of their capacity per year when not in use.[15]

3.3 Various Types of Batteries and Their Mercury Content

All batteries operate in accordance with similar principles; however, each system has its own combination of materials that determines its capacity, output, and life span. Seven types of batteries are in common use:

- carbon-zinc batteries;
- high performance carbon-zinc batteries;
- manganese (alkaline) batteries;
- mercury oxide batteries;
- silver oxide batteries;
- zinc-air batteries; and
- lithium batteries.

In most of these batteries, the cathode, which provides the anode oxidizing agent, consists primarily of the metallic oxide. Without exception, the anode is made up of a metal that corrodes in the electrolyte to various degrees.

All types of primary cells, with the exception of lithium batteries, contain mercury, which is mainly used as a passive inhibiting element. It is present in varying quantities, depending upon the system. Various compounds (Tables 4, 5 and 6) are added to the electrodes and/or the electrolyte in each type of cell, in order to increase its performance by controlling undesirable reactions, and to facilitate desirable reactions inside the

Table 4 Principal Components of Primary and Secondary Cell Systems

System	Cathode	Anode	Electrolyte	Hg content (% in weight)
Carbon-zinc batteries	Manganese dioxide	Zinc	Ammonium chloride	0.01
High-performance carbon-zinc batteries	Manganese dioxide	Zinc	Ammonium chloride	0.01
Manganese (alkaline) batteries	Manganese dioxide	Zinc powder	Potassium hydroxide	0.5 to 1
Mercury oxide batteries	Mercury oxide	Zinc powder	Potassium or sodium hydroxide	~ 33
Silver oxide batteries	Silver oxide	Zinc powder	Potassium or sodium hydroxide	1
Zinc-air batteries	Oxygen from the air	Zinc powder	Potassium hdyroxide hydroxide	1
Lithium batteries (Li-MnO_2)	Manganese dioxide	Lithium	-	-
Ni-Cd secondary batteries	Nickel oxide	Cadmium	Potassium or sodium hydroxide	-

Sources: 3 and 21

Table 5 Composition of Primary Cells (in %)*

Type of cell	Zn	MnO_2	Hg	Ag	Carbon	Paper/ Plastic	Steel	Cd	Li
Carbon-zinc	17	29	0.01	-	7	10	16	0.08	-
Mn (Alkaline)	14	22	0.5 to 1	-	2	5	37	-	-
Mercury oxide	11	-	33	-	-	7	22	-	-
Silver oxide	10	-	1	27	-	7	22	-	-
Zinc-air	30	-	1	1	?	7	60	-	-
Lithium	-	-	-	-	-	7	60	-	10 to 30

Source: 23

* The percentages do not add up to 100 percent, because not all components are listed.

Table 6 Global Reactions of the Main Types of Primary Cells

Type of battery	Charging Reaction	Discharging Reaction
Carbon-zinc	$2MnO_2 + 2NH_4Cl + Zn$	$2MnOOH + Zn(NH_3)_2 Cl_2$
Mn (Alkaline)	$Zn + 2H_2O + 2MnO_2$	$Zn(OH)_2 + 2MnOOH$
Mercury oxide	$Zn + H_2O + HgO$	$Zn(OH)_2 + Hg$
Silver oxide	$Zn + H_2O + Ag_2O$	$Zn(OH)_2 + 2Ag$
Zinc-air	$2Zn + 2H_2O + O_2$	$2Zn(OH)_2$

Sources: 16 and 22

battery. In mercury batteries, mercury is an active component (cathode) and accounts for one-third of the total weight of the battery.

The electrolyte participates in the chemical reactions produced inside the batteries. In dry batteries, the electrolyte is immobilized in the form of a paste or gel, or immersed in a separator.[16] The other battery components are inactive, and are made of metal (lead, steel, etc.), or combustible materials (plastic, paper, and cardboard).[22]

Figures 3 and 4 illustrate the cross sections of a cylindrical battery, and a button battery. Note that the metal jacket of the button battery acts as a terminal, and that it is frequently made of nickel-plated stainless steel.

The possibility of substituting the various types of batteries for each other is limited to certain applications.

3.3.1 Carbon-Zinc Batteries

Carbon-zinc batteries, also called Leclanché batteries, saline batteries, or ordinary batteries, are the best known, least expensive, and least powerful batteries. They hold the largest share of the world battery market.[21]

Recommended for their light and intermittent charges, they are often used for low power output devices, such as flashlights, radios, etc.[10] They are not suitable for sudden or sustained output demands. Carbon-zinc batteries have a tendency to leak when left in the host device after they are discharged.[15]

This category includes "high-performance" carbon-zinc or zinc-chloride batteries. These batteries are more expensive, and better able to withstand temperature variations than regular carbon-zinc batteries. High performance batteries last about 40% longer than regular carbon-zinc batteries, they have improved discharge characteristics, as well as a higher resistance to leaking[21], but they are not very suitable for applications that require high electricity outputs.[15]

The anode of carbon-zinc batteries is zinc, and the cathode contains manganese dioxide. The electrolytes consist of an aqueous solution of zinc chloride, in the case of "high performance" batteries, and ammonium chloride, in the case of ordinary batteries. During discharge, the zinc anode is oxidized, and the manganese dioxide is reduced.[24] Small quantities of several inhibiting agents, such as mercury chloride, can be used in the electrolyte. On average, 0.01% of the total weight of carbon-zinc batteries consists of mercury, and they are the only primary cells that contain cadmium.[25] In effect, a small quantity of cadmium is added to the zinc in the manufacture of the zinc can anode, which represents about 0.01% of the total weight of the battery.[25] The small quantities of mercury and cadmium used in carbon-zinc batteries pose minimal environmental hazard.

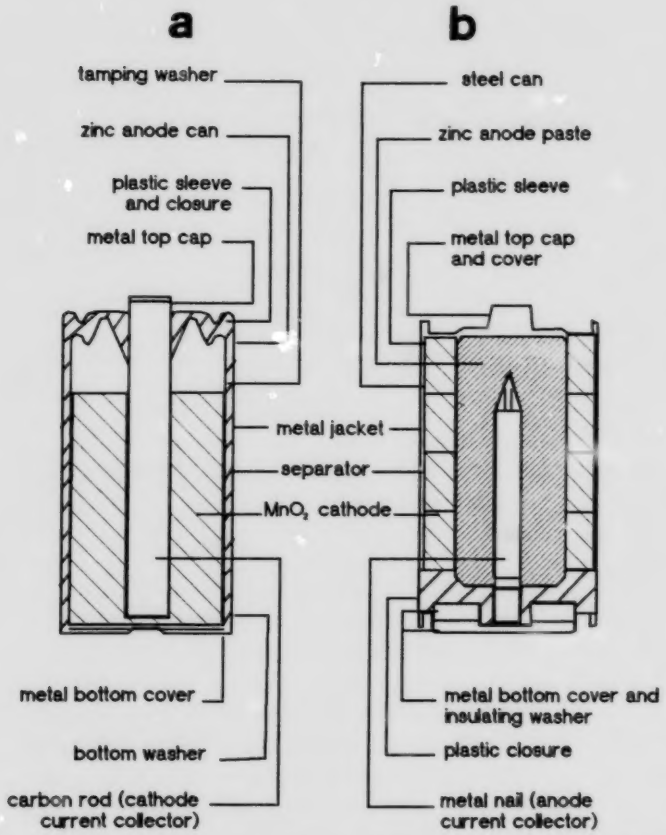


Figure 3 Cross Sections of Carbon-zinc (a) and Alkaline (b) Batteries[16]

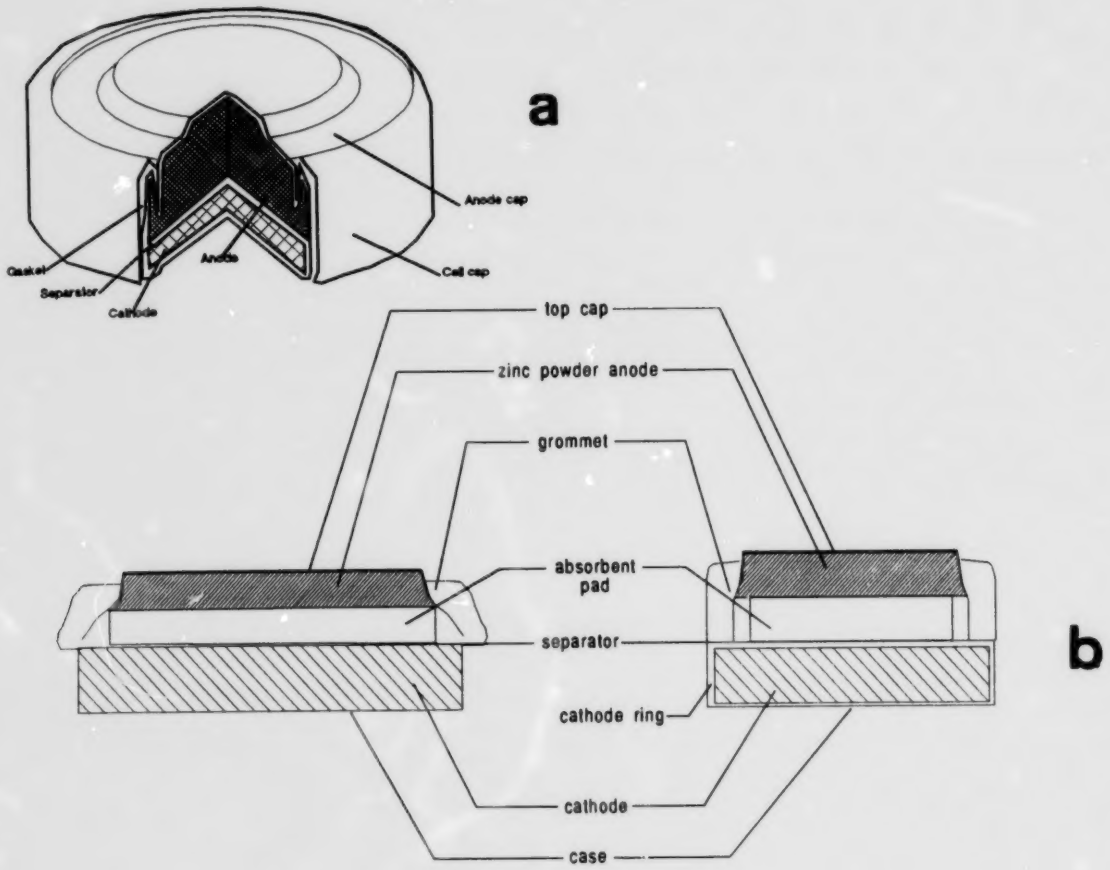


Figure 4 Cross Sections of Silver Oxide (a) and Mercury Oxide (b) Batteries

3.3.2 Alkaline Batteries

Since their introduction into the market at the end of the 1950s, the market share of manganese dioxide (alkaline) batteries (called long-lasting batteries) has continued to grow quickly, particularly since the end of the 1970s. Alkaline batteries were developed by replacing the active component of mercury oxide batteries (mercury oxide) by manganese dioxide.[21]

Manganese (alkaline) batteries are high performance batteries, and are much more expensive than carbon-zinc batteries. Figure 3 shows cross sections of carbon-zinc and alkaline batteries. Their energy density is higher than that of carbon-zinc batteries, but lower than that of mercury oxide batteries.[26]

They lose their capacity at a rate of only 2% after 12 months, an insignificant amount as far as the user is concerned.[23] A single alkaline battery can replace 3.5 ordinary batteries, or 2.5 high-performance batteries.[15]

These high-performance batteries are used for high current demand applications or for devices that use current over long periods of time. Alkaline batteries operate on a completely different principle than that used by carbon-zinc batteries, and they have superior electrical qualities.[14] They are also

resistant to high temperatures, and offer better safety where leaking is concerned.

Alkaline batteries have enjoyed great success during the past ten years, with the arrival of high-energy consumption devices, such as tape recorders, portable lights, camera lamps, photographic cameras, motorized toys, etc.[10]

The chemical reaction in alkaline batteries takes place in an alkaline medium.[15] The anode of alkaline batteries consists of zinc powder, and has a surface about 100 times more efficient than that of carbon-zinc batteries.[21] However, because of the particular shape of the anode, alkaline batteries require a much larger quantity of mercury than carbon-zinc batteries.[27] Typically, mercury accounts for 1% of the total weight in alkaline batteries, but it varies between 0.5% and 1%, depending upon the country. In Switzerland, for example, alkaline batteries contained 0.8% of mercury in 1987.[28] Measures to lower the mercury content of alkaline batteries from 1% to 0.15% by 1990, have been adopted in several Western European countries, and in Japan.[14] Note that the primary metal used in alkaline batteries is manganese.

3.3.3 Mercury Oxide Batteries

Mercury batteries are galvanic elements containing a mercury oxide electrode. Batteries using an aqueous system based on mercury oxide and zinc, were first made available in the United States in 1940 to replace batteries of the Leclanché type.[21] These batteries, then known as Ruben-Mallory or RM batteries,[16] revolutionized the battery industry. The International Electrochemical Commission suggest the use of the term "mercury oxide-zinc batteries" (HgO-Zn) for these cells. Mercury oxide batteries contain high energy for a given volume and weight, they have a long shelf life, and their voltage discharges at a relatively constant rate.

Most mercury oxide batteries are made in the button format. Mercury batteries have certain technical advantages, such as a high discharge capability over a long time, good stability during discharge, and the possibility of delivering very high-intensity power instantaneously. They are used to power electric watches, hearing aids, cameras, electrical instruments, acoustical devices, ultra-thin calculators, transmitters, electronic games, etc. Larger cylindrical mercury oxide batteries are designed in the same way, and are used in photographic devices and exposure meters.

The mercury oxide battery system has charged little since it was first introduced. It is based on an anode of amalgamated zinc powder, and a cathode made up of mercury oxide powder that has been incorporated into the internal surface of the casing, in order to ensure a good electronic contact. During discharge, the mercury oxide is converted into fine droplets of metallic mercury. The commonly used mercury oxide batteries for watches and hearing aids weigh about 2.5 g, and about 30% of their total weight consists of inorganic mercury.[23,29] A study done in Japan has shown that some of the mercury contained in these batteries is in the form of methyl mercury.[30]

3.3.4 Silver Oxide Batteries

Silver oxide-zinc batteries (Ag_2O-Zn), commonly known as silver oxide batteries or silver batteries, are similar to mercury oxide batteries (see Figure 4). The only difference is that their cathode consists of silver oxide. They were first marketed in the United States in 1961, shortly after the introduction of electric watches.

Silver-oxide batteries offer almost the same advantages as mercury batteries, but they are more expensive. Like mercury oxide batteries, most silver oxide batteries are marketed in the button format. They have the same applications as mercury oxide batteries, and there are no technical obstacles when replacing mercury oxide batteries with silver oxide batteries.[10]

The cathode of silver oxide batteries consists of Ag_2O-graphite, and the anode is zinc. One percent of the total weight of silver oxide batteries is mercury. Silver oxide batteries used in hearing aids generally contain a potassium hydroxide electrotyle; the silver oxide used in watches, however, contain a sodium hydroxide electrolyte.[20]

3.3.5 Zinc-Air Batteries

Zinc-air batteries in the button format were introduced a few years ago. They are used as a source of power for hearing aids, and are progressively replacing the use of mercury oxide batteries. Less polluting, zinc-air batteries have a greater capacity than mercury batteries.[10]

The zinc-air system is different from other types of batteries, because its cathode is made up of active carbon, where oxygen becomes electrochemically active. The air is introduced into the casing through holes which, before the battery is used, are covered with a movable metal seal. Once the seal is removed, the battery discharges relatively quickly (in about three months), even when it is not connected to a device. This is not a disadvantage when this type of battery is used to power hearing aids.[14] In fact, regardless of the type of button batteries used in this application, the battery must be replaced frequently. Zinc-air batteries contain about 1% mercury, which is used as an inhibitor.

3.3.6 Lithium Batteries

The first lithium battery prototypes were introduced around 1960.[20] At that time, there was some danger of explosion, because the lithium was highly reactive with water or the oxidizing agent. This risk has been controlled by using special containers and non-aqueous electrolytes. Lithium batteries contain neither mercury nor cadmium, and are well-known for their long life span (about five years).[17] Their voltage is almost double that of other types of batteries. Lithium batteries are commonly used for military applications, especially in communications equipment (portable radio transmitters, transmitter-receivers, acoustic radio beacons).[16]

The popularity of lithium batteries has increased in the last five to seven years.[10] They are generally used in the button format for domestic and medical applications, and as a source of power in watches, calculators, pocket games, etc. These batteries are also widely used to power printed circuits in computers.[15]

Lithium batteries weigh less than other battery systems. Lithium has one of the highest electrochemical potentials when used as the anode material, and its low weight (about thirty times less than the weight of lead[20]) is a great asset. Lithium systems can be used in a variety of configurations, depending upon the application. The most popular lithium batteries are manganese dioxide batteries ($LiMnO_2$) which operate at 3 V.[17] In this system, the anode consists of the metallic lithium, and the cathode of manganese dioxide. This type of battery does not contain mercury.

3.4 Role and Concentration of the Mercury Used in Batteries

Of all the heavy metals used in the manufacture of primary and secondary cells, lead, cadmium, and mercury are of most concern. The amount of mercury consumed for the fabrication of primary cells has increased in the last few years to the point that it now represents the principal use of mercury in some countries (Figure 5). Alkaline batteries account for most of the mercury used in electric batteries[6]. Note that most of the electric batteries used in Canada are manufactured in other countries, particularly in the United States and Japan. About half of the mercury consumed each year in the United States is used in the electric battery industry.[2]

Mercury is used as an inhibitor, and is added to the zinc anode (in most primary cells) to prevent corrosion mechanisms from affecting the chemical reaction through the generation

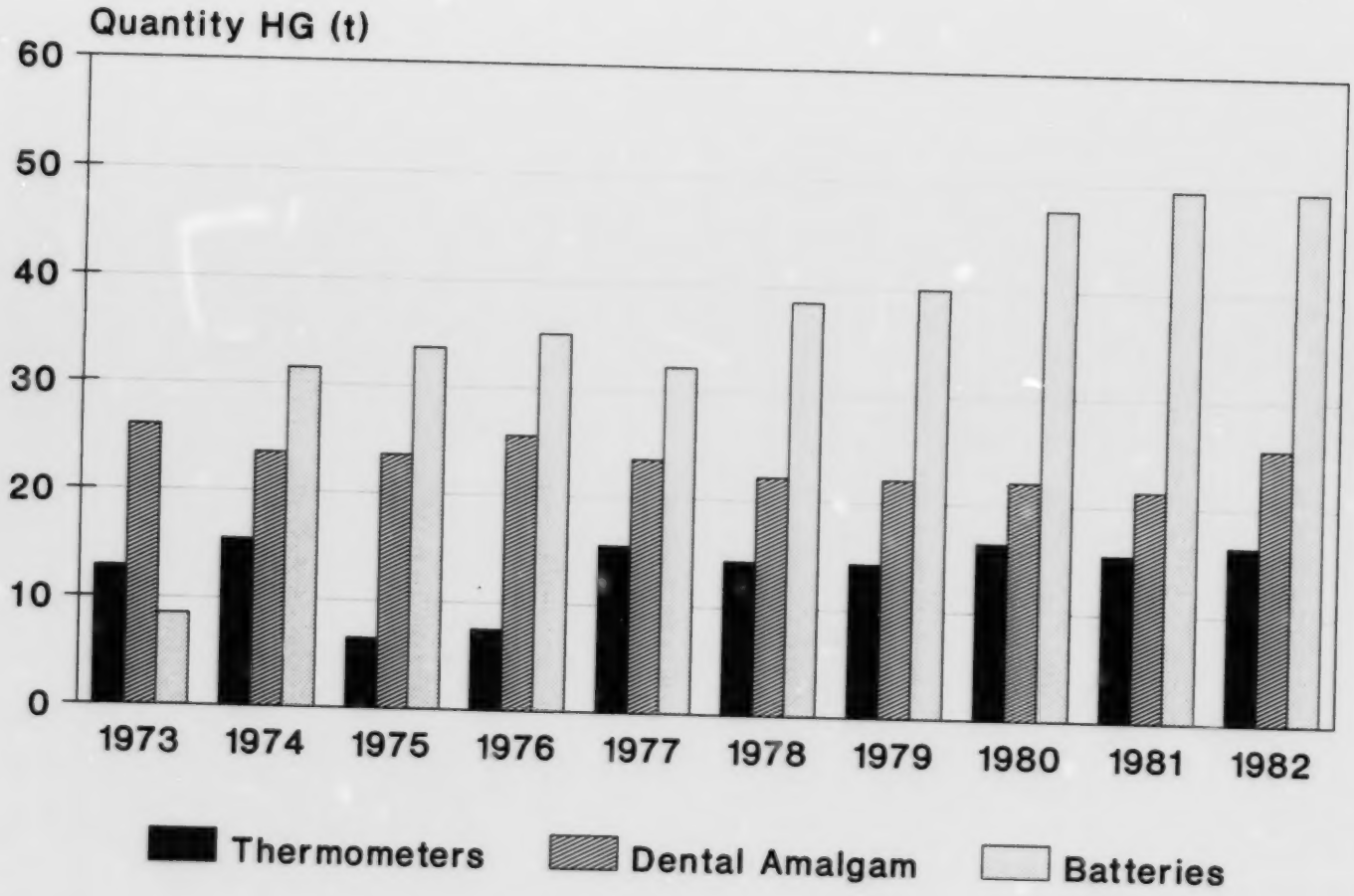


Figure 5 **Use of Mercury in the Federal Republic of Germany from 1973 to 1982** [32]

of gas.[10] The presence of mercury also prevents the batteries from self-discharging; its presence, therefore, considerably extends the shelf life of the product.[25] With the exception of lithium batteries, all primary cells contain mercury, which is generally used as a passive component. Mercury is also used as the cathode in mercury oxide batteries; in these applications, the properties of mercury are unique. The consumption of mercury batteries is decreasing, however, and according to various sources, it will be almost nil ten years from now.[31]

The mercury content of mercury oxide batteries is about 30% of their total weight. Depending on the battery size, the mercury oxide content ranges between 0.3 g and 1.5 g.[29]

A little-known fact is that alkaline batteries contain significant quantities of mercury in the form of amalgamated zinc powder. In many countries, the powder is a greater source of mercury than mercury oxide button batteries. Depending on the standards imposed by the country, alkaline batteries contain between 0.5% and 1% mercury. Researchers in the United States and Japan have shown that it is possible to significantly reduce the quantities of mercury used, but this requires a development and investment effort. For example, the addition of a trace of indium to the zinc can reduce the amount of mercury required by 50%.[21]

Only about 0.01% of the total weight of carbon-zinc batteries is mercury;[33] thus, they do not represent a threat to the environment.

3.5 Various Types of Secondary Cells

Contrary to primary cells, secondary cells are reversible over several hundreds of cycles, if external energy is supplied.[16] Since they can be charged and discharged, secondary cells are used to store the electrical energy supplied by an external source. There are many types of secondary cells (Table 7), but the most widely used are the traditional lead secondary cells (lead-lead dioxide with a sulphuric acid electrolyte), and nickel-cadmium secondary cells, which are becoming increasingly popular. (Discharging reactions of various types of secondary cells is given in Table 8).

Recently, a new type of secondary cell using lithium has been marketed.[34] Moli Energy Limited of Burnaby, British Columbia, produces 4 000 of these cells each year in its pilot plant. This Canadian firm is at the international forefront of rechargeable lithium battery technology. Moli Energy predicts that its installations will significantly develop by 1990.[35]

3.5.1 Nickel-Cadmium Secondary Cells

The manufacture and use of nickel-cadmium secondary cells began during the late 1950s. They are used in various industrial and communications applications.

There are two types of nickel-cadmium secondary cells: gas-tight (or sealed), and open. With the exception of the electrolyte, these secondary cells are not significantly different from each other. Large nickel-cadmium cells of the open kind are rectangular in shape, and similar to lead cells,

Table 7 Types of Secondary Cells

Lead-acid	Zinc-air
Alkaline-manganese	Sodium sulphide
Silver-zinc	Nickel-hydrogen
Silver-cadmium	Silver-hydrogen
Nickel-zinc	Lithium

but offer better performance. They are normally used for industrial applications, and have a life span of about 10 to 30 years, depending upon the tasks involved (electric vehicles, emergency power source, etc.).[18]

Small gas-tight or sealed secondary cells, commonly known as rechargeable Ni-Cd batteries, are made in the button and cylindrical formats and can theoretically be recharged more than 1 000 times. Rechargeable batteries, or gas-tight nickel-cadmium secondary cells used for domestic applications are by far the cheapest to use. The composition of the electrodes in the gas-tight cells eliminates excess pressures from the emission of oxygen during overload conditions.[14] Secondary cells have a life span of about five years (sometimes a warranty is given to this effect), and like primary batteries, are used in tools, radios, tape recorders, flashlights, calculators, medical devices, measuring instruments, communications equipment, etc. Rechargeable nickel-cadmium batteries have a lower energy density than primary cells; the capacity of rechargeable Ni-Cd batteries is equivalent to one-fifth that of alkaline batteries.[10] Rechargeable Ni-Cd batteries are not recommended for emergency power supply systems (for example, smoke detectors), because they discharge quickly, and could be dead at the time of an emergency. On the other hand, Ni-Cd batteries have the advantage of offering more uniform power during use.[36]

As their name indicates, the active elements in Ni-Cd secondary cells are nickel, which is the cathode; and cadmium, which is the anode. The cadmium content is generally lower than that of nickel, and represents about 15% of the total weight (Table 9).[10] When the secondary cell is charged, the nickel hydroxide is oxidized, and the cadmium hydroxide is reduced to its metallic form.[18]

Table 8 Charging and Discharging Reactions of Various Types of Secondary Cells

Type of secondary cell	Charging Reaction	Discharging Reaction
Lead	$Pb + 2H_2SO_4 + PbO_2$	$PbSO_4 + 2H_2O + PbSO_4$
Ni-Cd	$2\ Ni(OH)_2 + Cd(OH)_2$	$2NiO(OH) + Cd + 2H_2O$

Sources: 18 and 22

Table 9 Proportion of Nickel and Cadmium Contained in Various Types of Nickel-Cadmium Secondary Cells

Type of Ni-Cd secondary cell	Nickel (%)	Cadmium (%)
Open system	12	10
Gas-tight system (button)	32	15
Gas-tight system (cylindrical)	20	18

Source: 37

Section 4

Consumption of Batteries

Batteries, which were for a long time considered to be specialized technical products, are now widely consumed in the domestic market. The world market for primary and secondary cells is in the billions of dollars. In 1984, for example, it was 19 billion dollars (Table 10). Primary cells (alkaline, carbon-zinc, lithium, and other types) accounted for seven billion dollars of this amount.[11] In Japan alone, three billion batteries were produced in 1984.[27] In the United States, the battery market amounted to 2.5 billion dollars in 1985, and should reach 3.3 billion dollars in 1990.[38] The total battery market in the United States is increasing by 5% each year[39] and according to NEMA (National Electrical Manufacturers' Association), the market for alkaline batteries is increasing by 9% per year.[38]

4.1 The Market for Carbon-Zinc and Alkaline Batteries

Alkaline and carbon-zinc batteries hold the largest share of the domestic battery market (about 90%), in terms of sales, tonneage and numbers of batteries.

Traditional carbon-zinc and mercury batteries have long been used as energy sources for most portable electronic applications. Nevertheless, the use of carbon-zinc batteries is decreasing, whereas the use of alkaline batteries is increasing.[10] Considering consumption in developing countries (which use fewer "top of the line" models), it is estimated that 80% of the batteries sold throughout the world are carbon-zinc batteries.[10]

Table 10 World Market for Primary and Secondary Cells*

Type	Estimate* (billions of $)	Annual market growth (%)
Alkaline	3.0	5-6
Carbon-zinc	3.0	0
Lithium	0.3	40
Others	0.6	n/a
Ni-Cd	1.1	20-25
Lead	11.0	3-5
Total	19.0	

Source: 11

* for 1984

(Note that the evaluations of battery consumption in this chapter do not consider military uses; such information is either restricted or difficult to obtain).

Carbon-zinc batteries use only a small percentage of mercury compared with that in alkaline batteries, although their weights are relatively similar. The phenomenal expansion in the market for alkaline batteries in the last decade has therefore led to a significant increase in the use of mercury.

In 1975, when the Duracell firm carried out its first televised advertising campaign in the United States, the consumption of alkaline batteries accounted for 15% of the American market. In the next 10 years, the share of the American market held by alkaline batteries reached 60%, (Table 11) and according to Duracell, they will hold 75% of the market by 1990.[38] The market for dry cells in the United States has almost doubled since 1980.[20] The Duracell and Eveready (Energizer) companies each hold 45% of the American market for alkaline batteries, followed by Ray-O-Vac, which holds 5% of the market.[38] During this period, carbon-zinc batteries were replaced by alkaline batteries, with a 30% increase in the number sold.[11]

Unlike the American market, one out of three batteries bought by European and Japanese consumers is a carbon-zinc battery; however, the situation is changing rapidly in favour of alkaline batteries. Although there is an increasing demand for small alkaline batteries to the detriment of the larger formats;[10] the "AA" size hold about 40% of the sales of this type of battery in the United States.[38]

In the industrialized countries, average per capita battery consumption has been estimated to vary between 7 and 15 batteries per year, depending on the country and the period of analysis. A study carried out by the Duracell company revealed that American consumers bought two billion batteries to operate 900 million devices in 1985. The average American family owns ten battery-operated devices, and buys about 32 batteries per year.[38]

In the United States and Canada, alkaline batteries are heavily advertised; many retailers sell only this type of battery. In Japan, although battery consumption is high, purchases are made frugally. The reason is that buyers have learned to take advantage of the low cost of carbon-zinc batteries for appropriate applications (for example, intermittent use and low energy outputs). It is important to emphasize however, that rechargeable nickel-cadmium batteries are now threatening the privileged position of alkaline batteries.

4.2 The Market for Button Batteries

Microelectronics and miniaturization have encouraged the production of increasingly affordable devices. The production of

Table 11 Proportion of Unit Sales of Alkaline Batteries

Country	Alkaline batteries Units (%)
United States	60
Switzerland	40
France	35
Federal Republic of Germany	25
Austria	30
The Netherlands	30

Sources: 10, 23, 40, and 41

miniature electronic instruments has led to a heavy demand for miniaturized power sources offering greater energy density and better discharge characteristics than those of traditional batteries. For example, in 1979, Japan produced over 45 million electronic calculators. During the same year, 260 million watches were sold; a third of these were electric watches.[16] With the exception of mechanical watches, almost all of today's watches derive their energy from button batteries.

After a period of rapid growth, the market for button batteries has begun to stabilize.[23] The use of mercury oxide batteries is gradually decreasing as they are replaced by other chemical systems.[3] Mercury oxide batteries are being replaced mainly by silver oxide batteries in watches and calculators; while zinc-air batteries are being increasingly used to supply energy for hearing aids. In response to a request made by Japanese authorities in 1984, the Japan Battery and Appliance Industries' Association stated that no new applications for mercury batteries would be developed.[27] In some cases, solar batteries can replace mercury batteries for low energy requirements, such as liquid crystal calculators and watches.[36]

In France, most mercury oxide batteries sold in 1981 were used in hearing aids; while most silver oxide batteries were used to power watches.[42] Table 12 shows the use of button batteries in France in 1981. Today, the distribution is somewhat different, due to the increased consumption of lithium and zinc-air batteries.

Table 13 shows the distribution of mercury oxide consumption in West Germany in 1983.

Table 12 Use of Button Batteries in France in 1981

Use	Batteries HgO (%)	Ag2O (%)	Other (%)
Hearing aids	98	2	--
Photography	43	30	27
Watches	4	95	1
Calculators	34	--	66

Source: 42

Table 13 Use of Mercury Oxide Batteries in the Federal Republic of Germany in 1983

Use	%
Hearing aids	50
Photography	48
Watches	1
Other	1

Source: 42

4.3 *The Market for Rechargeable Nickel-Cadmium Batteries*

The market for rechargeable nickel-cadmium batteries is constantly growing; therefore, the possibility of replacing primary cells with nickel-cadmium batteries must be considered. Primary cells are an expensive way to obtain energy, and it is predicted that the market share for the more cost-effective secondary cells or rechargeable batteries will show steady growth[16] as they replace primary cells, but no drastic measures are predicted to occur over the next five to ten years.[18] The consumer often prefers the convenience of primary cells, which are ready to use whenever they are needed. Rechargeable batteries have a marked tendency to discharge when not in use, and must be periodically recharged.

In Japan, over 220 million rechargeable nickel-cadmium batteries were produced in 1984, a 25% increase over previous years. Most rechargeable Ni-Cd batteries are made in the United States and Japan.

4.4 *Trends and Developments in the Canadian Market for Primary and Secondary Cells*

Battery consumption in Canada is similar to that in the United States. Canada is, not surprisingly, the main client of the American battery industry.

The audio field and electronic games have accounted for the highest increase in the use of batteries (Table 14).

The Canadian battery market increased by 62% between 1982 and 1986 (Figure 6). The market for alkaline batteries is still dominant and has grown even more rapidly than the total battery market (Figures 7 and 8). In 1986, alkaline batteries accounted for over 66% of all battery sales; the sale of rechargeable batteries more than doubled between 1982 and 1986, increasing from 3% to 8% of total battery sales (Table 15).

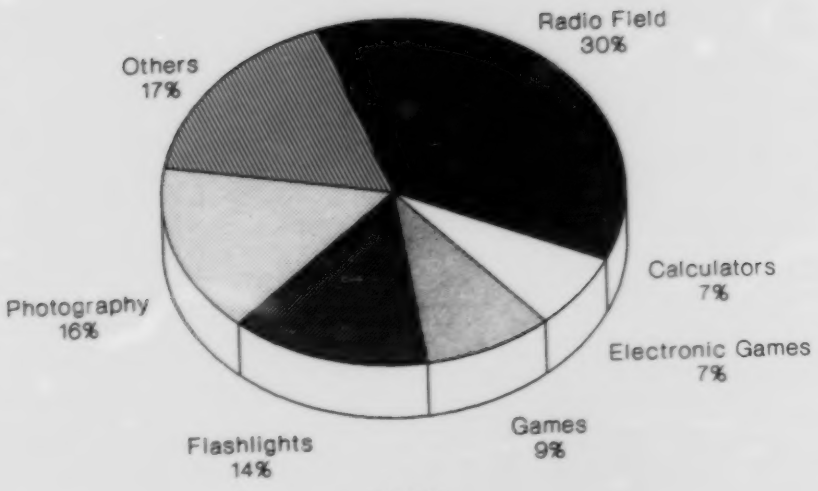
The use of the "AA" format has increased considerably during the last few years (Table 16), from 31% in 1982 to 47% in 1986 (Figure 9). The use of "C" and "D" batteries has also increased during the same period, but the great increase in the use of "AA" batteries has cut into the "C" and "D" market share[11] (Figure 9).

Most batteries sold for electric watches are silver oxide button batteries. Mercury oxide batteries are still used for hearing aids, but they are gradually being replaced by zinc-air batteries.

Table 14 Use of Electric Batteries in Canada

Application	1982 (%)	1986 (+ 62%)
Audio	30	30
Photography	16	14
Toys	9	15
Flashlights	14	12
Electronic games	7	2
Calculators	7	2
Other	17	10
Smoke detectors		5
Switches		4
Watches, clocks		6

Source: 11, Canadian Battery Market, Application Trends



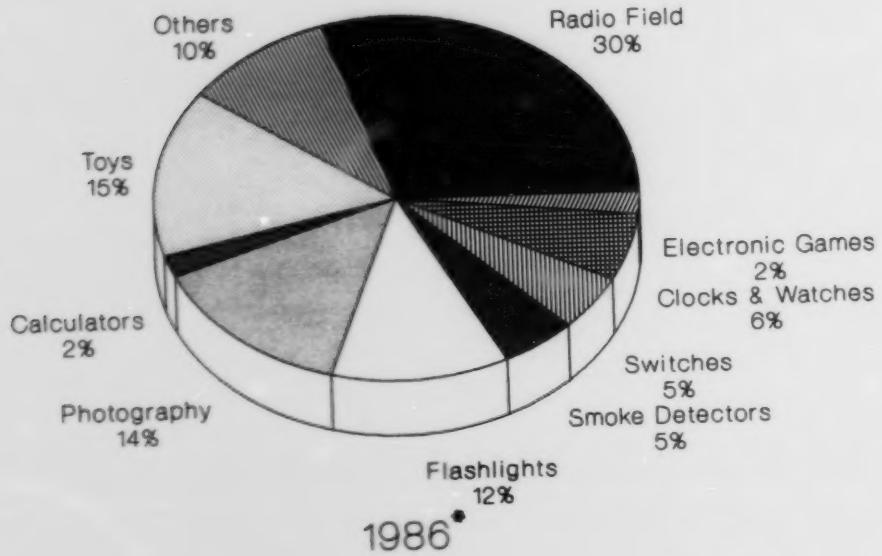


Figure 6 **Use of Batteries in Canada, 1982-1986[11]**
*** + 62%**

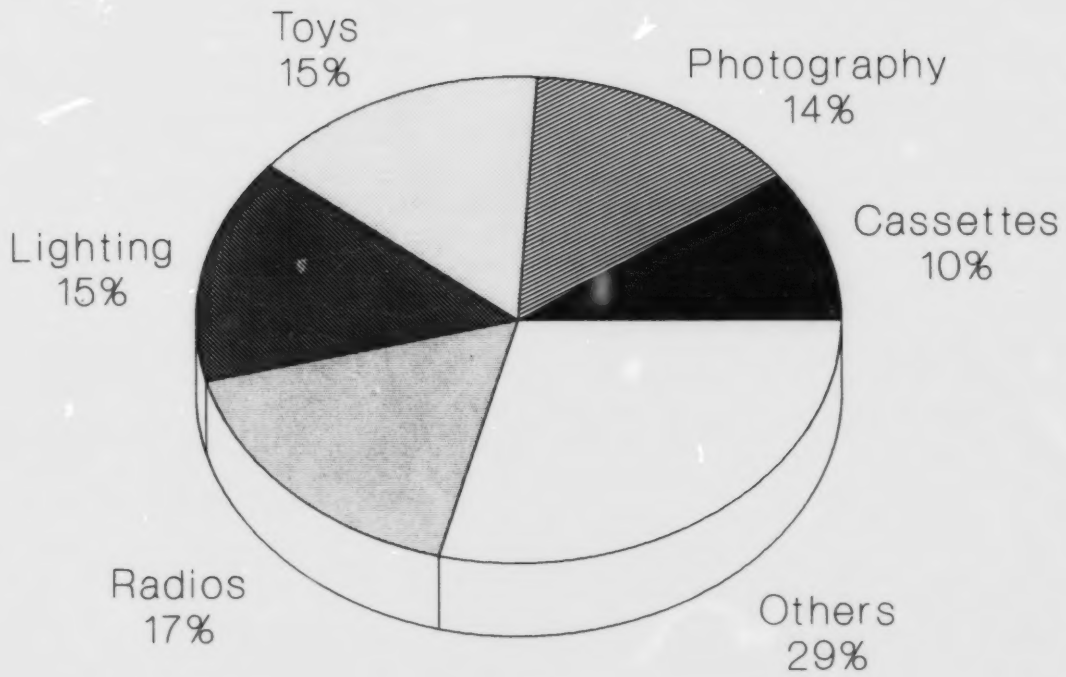
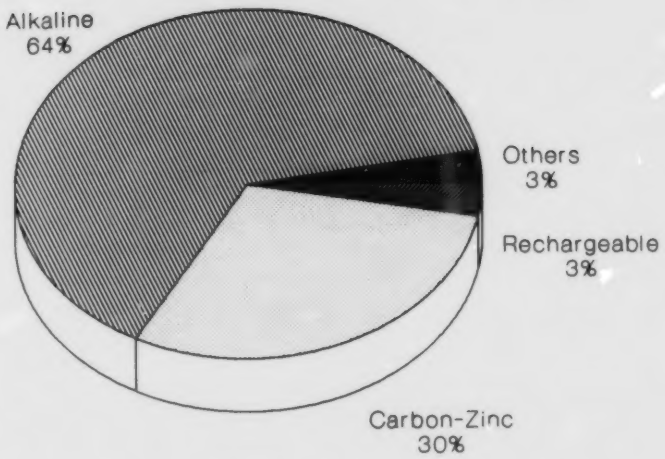
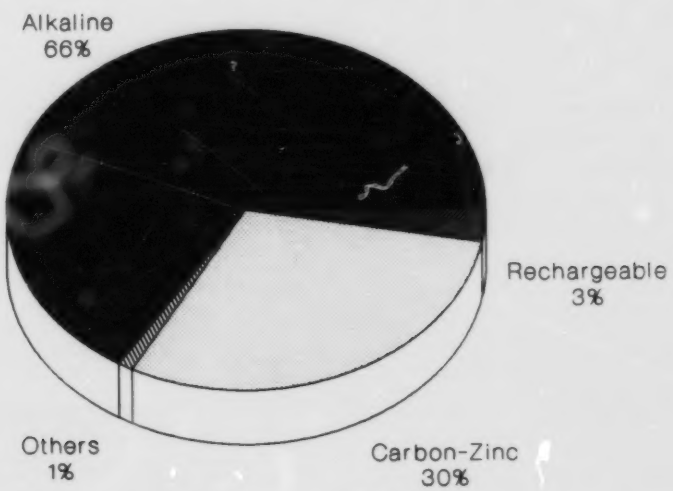


Figure 7 **Use of Batteries in Canada in 1987[11]**



1982



1986*

Figure 8 **Types of Batteries Sold in Canada Between 1982 and 1986, Canadian Battery Market[11]**
*** + 62%**

Table 15 Trends in the Battery Market in Canada

Type of battery	%
Ni-Cd	20-25
Alkaline	5-6
Lithium (primary cell)	40
Carbon-zinc	0

Source: 11

Table 16 Battery Formats Used in Canada

Format	Carbon-zinc batteries (%)	Alkaline batteries (%)
AA	41	54
C	21	15
D	24	16
9 V	12	10
Other	2	5

Source: 11

The most popular battery brands sold in the country include Duracell, Eveready (Energizer), and Mallory. In Canada, the Duracell company sells mainly alkaline batteries; some are manufactured in Ontario, and the rest are imported from the United States.[43] There is ferocious competition between Duracell and Eveready (Energizer)[11] alkaline batteries. The Eveready company is acquiring an increasing share of the alkaline battery market, while the sale of its carbon-zinc batteries is greatly diminishing.[11] A significant number of batteries also come from Japan, Taiwan, and Hong Kong; often, these batteries are used in imported electronic products.

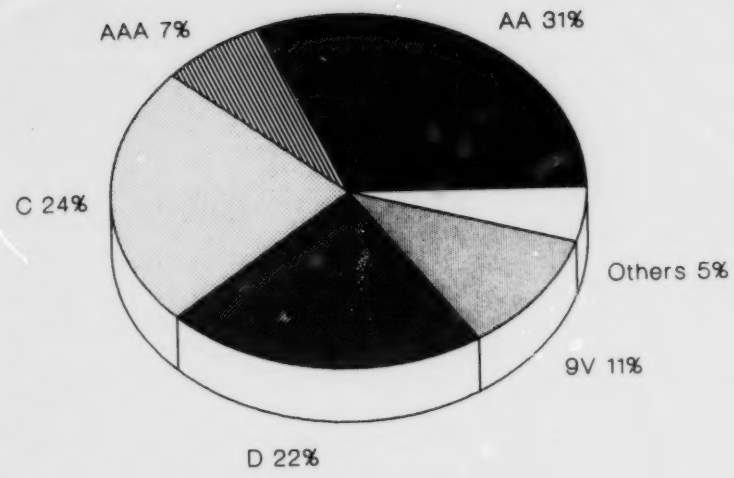
Most of the batteries sold in Canada are purchased in hardware stores. However, the proportion of batteries sold in pharmacies has substantially increased: from 9% of battery sales in 1982 to 16% in 1986 (Table 17).

Tables 14, 15, 16, 17, and 18 describe the Canadian battery market.

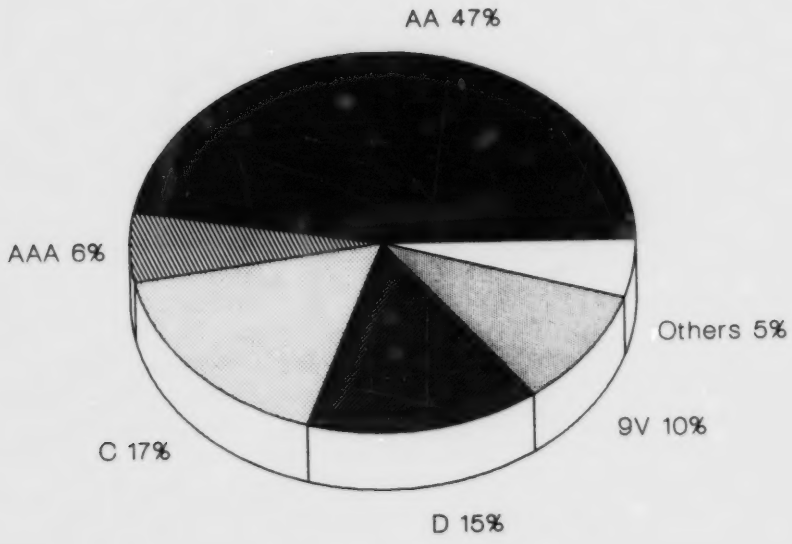
4.5 Market Developments and Trends

For various reasons, battery manufacturers are not willing to provide data on their sales and consumption of mercury; unfortunately, most of the information requested remained unanswered.

Battery manufacturers are constantly searching for modifications to improve their products' performance. Recently, research has focused on the development of batteries with higher capacities, such as silver oxide-zinc, zinc-air, and alkaline batteries. The development of new applications for batteries has been counterbalanced by new techniques that consume less energy. Also, the use of batteries for medical purposes is increasing.[23]



1982



1986

Figure 9 **Formats of Batteries Sold in Canada Between 1982 and 1986, Canadian Battery Market[11]**

Table 17 Distribution of Battery Purchases in Canada

Commercial establishment	1986 (%)
Hardware store	21
Discount store	17
Grocery store	12
Pharmacy	16
Audio store	7
Camera store	3
Other	

Source: 11

Table 18 Percentage of Sales of Various Commercial Brands in Canada

Trademark	1982 (%)	1986 (%)
Duracell	44	44
Energizer	17	16
Eveready	20	17
RayOVac	4	4
Mallory	4	3
Dynacharge	2	3
Other	9	13

Source: 11

In general, the use of carbon-zinc batteries is decreasing, while the demand for alkaline batteries is increasing by 5% to 20% each year.[11,23,38]

The popularity of some types of batteries, such as mercury oxide batteries, is decreasing, while other types of batteries are being introduced on the market. In view of the controversy surrounding mercury batteries, their production will be increasingly curtailed.[12] Mercury batteries are being replaced by zinc-air, lithium, and alkaline button batteries. The sale of mercury batteries in EEC countries decreased by 30% between 1980 and 1983. The manufacturers maintain that in the next five or ten years, mercury batteries will only be used for certain applications, particularly those in the military field.[42] Modern electronic equipment requires ever-decreasing amounts of energy to operate, and this drop in the demand for energy is considerably affecting the battery market. Zinc-air and lithium batteries seem to hold the answer for the future.

All manufacturers are searching for the battery of the future, which will be smaller, more powerful, and less polluting than today's batteries. All evidence points to a growing battery market. The trend is toward high quality batteries, although it is unlikely that carbon-zinc batteries will disappear from the market. The use of nickel-cadmium secondary cells is expected to increase.[23]

Section 5

Mercury and the Disposal of Household Waste

5.1 Mercury in Household Waste

The problem originates from mercury in batteries that are discarded with household waste into sanitary landfill sites, incinerators, or more rarely, compost boxes. Composting, which was popular in Europe in the past, is decreasingly used as a method of final disposal. The growing presence of small quantities of hazardous waste is partially responsible for this decrease in popularity.

Consumer habits affect the composition and volume of waste. Household waste contains many undesirable products such as: drugs, insecticides, oil, paints, solvents, paint removers, smoke detectors, thermometers, fluorescent tubes, and used batteries. Europe has been in the forefront of managing small quantities of hazardous waste. In many countries, for example, citizens can telephone a government agent to inquire about the nearest site where they can properly dispose of their hazardous wastes. For example, Swiss citizens can (and are legally bound to) take back old drugs to their pharmacists, and used batteries to battery retailers.

Together, the member countries of the Organization for Economic Cooperation and Development (OECD) annually produce about 350 000 tonnes of small quantities of hazardous wastes. North American consumers are responsible for 150 000 to 175 000 tonnes of this amount[14].

Generally, North Americans generate much more waste than Europeans (see Table 19).

Used batteries contribute a significant proportion of the heavy metals associated with small quantities of hazardous wastes. Regardless of the method of waste disposal, mercury contained in discarded batteries will eventually migrate into the environment.

In 1970,[46] the total quantity of mercury present in household waste in the United States was estimated at 500 tonnes per year; today, used batteries alone are responsible for 1 000 tonnes of mercury.

There is no consensus on the environmental consequences of used batteries in household waste. A few scientific studies, which have usually been sponsored by the manufacturers,

Table 19 Quantity of Household Waste Produced Per Year

Country	Quantity of Waste (kg/inhabitant)
Europe	~ 300
The Netherlands	~ 338
Switzerland	~ 350
United States	~ 710
Canada	~ 666
OECD	~ 400

Sources: 8, 44, and 45

conclude that the concentrations of mercury in household waste are relatively small, and do not represent a problem.[3] However, other sources state that used batteries are an environmental hazard when they are discarded, composted, or more importantly, when they are incinerated with household waste.

5.2 *Mercury Emissions as a Function of the Method of Disposal*

Most industrialized countries face a serious problem of solid waste disposal; for some countries, this problem will soon reach a critical level. The odyssey of the New York garbage barge in 1987, spectacularly demonstrated the solid waste problem.

Everyone generates waste, but few people want to live near a waste-disposal site. This syndrome is known as "NIMBY" or "not in my backyard."

People seem more opposed to the construction of a sanitary landfill site than to the construction of an incinerator. Often, people consider the first to be a very rudimentary method of disposal, a makeshift last resort. In the last few years, incinerators have received very bad press. Apart from mercury, the emissions of dioxins, furans, polycyclic aromatic hydrocarbons (PCAs), etc. are becoming increasingly associated with incinerator use. Soon, incinerators will have to be equipped with better facilities to scrub combustion gases.

Composting is a waste disposal method that is rarely used in Canada; and even if it were used, batteries, as well as glass, metal, and plastics, must be removed from the waste before composting.

Regardless of the method chosen for final waste disposal, it is necessary to reduce the volume of waste produced, and participate in programs for selective collection and recovery.

5.2.1 *Sanitary Landfill Sites*

In most countries, sanitary landfill sites remain the common method of waste disposal; the use of incinerators, however, is increasing. Well-planned landfill disposal should include a program for the collection or monitoring of run-off and leachate water, and should prevent any environmental contamination.

Batteries discarded with household waste eventually corrode and deteriorate; this allows the mercury to leak out after a period of one to three years.[23] If the leachate is not properly collected and treated, some of the mercury will reach the groundwater and migrate toward a surface body of water. Unfortunately, this is often the case, and biological treatment cannot eliminate this problem.

When the organic matter from household waste undergoes anaerobic decomposition, large quantities of sulphide by-products are generated. Mercury, which has a great affinity for sulphur, combines with it on-site and is transformed into a highly stable and insoluble compound.[47, 48]

The result is that the soil becomes contaminated, and will not be suitable for re-use once the landfill operation is completed. Japan in particular, has come to grips with this problem. A study carried out by Gotoh (1986) found an average concentration of 3.0 mg/kg of mercury in the soil of Japanese sanitary landfill sites.[27]

Nevertheless, almost all authors agree that the sanitary landfill method involves fewer mercury contamination problems than incineration. Disposal using the sanitary landfill method is still less costly than other waste disposal methods. However, difficulties are commonly encountered in the search for disposal sites, and thus costs have increased accordingly.[44] For example, in Western Germany, the cost of municipal waste disposal increased by 50% during a

five year period, in nominal terms.[44] Projects have been carried out to make specific improvements in the disposal sites by studying: the water-tightness of the disposal site, the control of infiltration, the location for the best degassing installations, the monitoring of waste delivery, the inspection of the waste before evacuation, the use of special vehicles to compress the waste, and the implementation of long-term protection measures.

5.2.2 Incineration

Urbanization and the dependence of many industrialized countries upon imported energy, as well as the increasing cost of energy, mean that the incineration of household waste is becoming a more attractive and profitable solution in industrialized countries and regions with high population densities.[44] With incineration, the volume of waste can be reduced by 80 to 90%. The residual ash is subsequently collected and disposed of.

The quantity of waste incinerated in industrial countries has increased by more than 30% in the last five years. Canada incinerates a relatively small percentage of household waste (see Table 20).

Generally, municipal incinerators are not designed to destroy small quantities of hazardous wastes. Consequently, they emit heavy metals, dioxins,[51] and carcinogenic PCAs.[52]

The mercury contained in the waste is extremely volatile and vaporizes quickly during combustion. The result is that almost all of the mercury vapour bypasses the traditional purification equipment (mask or electrostatic filters), and is emitted into the atmosphere.[8] In the Netherlands and Western Germany, over 50% of the mercury emissions are attributed to municipal incinerators.[8,23,53] Alkaline batteries are the main source of these emissions.[23] The mercury recondenses in the atmosphere and then falls to the ground via precipitation. The presence of humidity facilitates the oxidation of mercury. Once the mercury is deposited in an oxide form, it can be re-emitted after a biochemical

Table 20 Proportion of Household Waste Eliminated by Incineration

Country	% of household waste incinerated	Year
Switzerland	80	1987
Denmark	75	1983
Japan	69	1984
The Netherlands	40	1983
Sweden	37	--
France	37	1983
Federal Republic of Germany	30	1983
Belgium	30	--
Italy	24	1983
England	14	1984
United States	12	1984
Canada	4	1986

Sources: 42, 45, 49, and 50

transformation into methyl mercury and dimethyl mercury.

The most polluting method of battery disposal is by incineration.[54] Electrostatic filters eliminate only 5% of the mercury contained in the combustion gases.[23] It is possible, however, to moderately reduce mercury emissions by using an adequate gas-scrubbing method. The results obtained by the National Incinerator Test and Evaluation Program (Canada - NITEP) clearly demonstrate that cooling the combustion gases is necessary to eliminate the mercury effectively.[55]

There are three general categories of combustion gas scrubbing equipment that are all based on gas-cooling:

- wet scrubbing;
- wet-dry scrubbing; and
- dry scrubbing with gas processing.

Wet scrubbing lowers the temperature of the combustion gases to about 70°C and very effectively reduces the mercury content. The dry method with gas processing lowers the temperature to about 140°C and permits the reduction of the mercury content by about 90%.[48,55]

Clearly, gas scrubbing equipment must be added to the traditional filters. The latter are only effective in reducing fly-ash pollutant.

All the toxic compounds retained by various means should undergo treatment before burial. Figure 10 illustrates the problems of used battery disposal using the traditional household waste disposal networks.

5.3 Cadmium in Household Waste

Cadmium is a stable chemical element that has multiple applications (electroplating, dyeing, etc.). However, it is toxic - more toxic than mercury. The effects of cadmium on human health mainly result from ingesting contaminated foods; the principal effects are carcinogenic and teratogenic. Cadmium also affects the liver, kidneys, lungs, blood (anemia), and it can cause cardiovascular or high blood pressure problems. It has a long biological half-life, and can become concentrated in the food chain. It has also been identified as one of the most mobile of the heavy metals, particularly in the soil.[8]

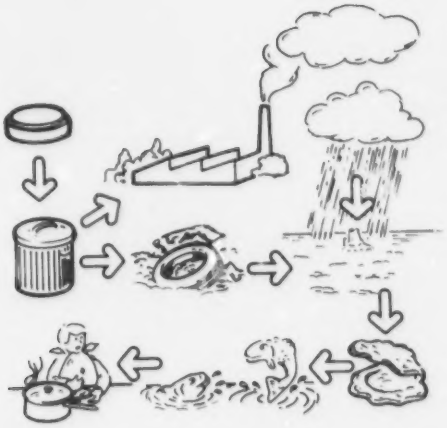
The consumption of cadmium for the manufacture of secondary cells or rechargeable batteries has increased considerably, notably in Japan and the United States.[18] It has been estimated that the cadmium consumption related to the manufacture of secondary cells in Western Germany, the United Kingdom, Japan, and the United States increased from 8% in 1970, to 29% in 1982. The authors estimate that roughly 33% of the total cadmium used in 1984, was for the manufacture of secondary cells.[18]

In 1984, cadmium consumption was seven times higher than in 1970 (see Table 21).

Table 21 Trends in the Consumption of Cadmium in the Manufacture of Primary and Secondary Cells

Year	United States (t)	Japan (t)	EEC countries (t)
1960	230	20	-
1970	174	176	-
1984	1 141	1 389	1 375

Source: 18



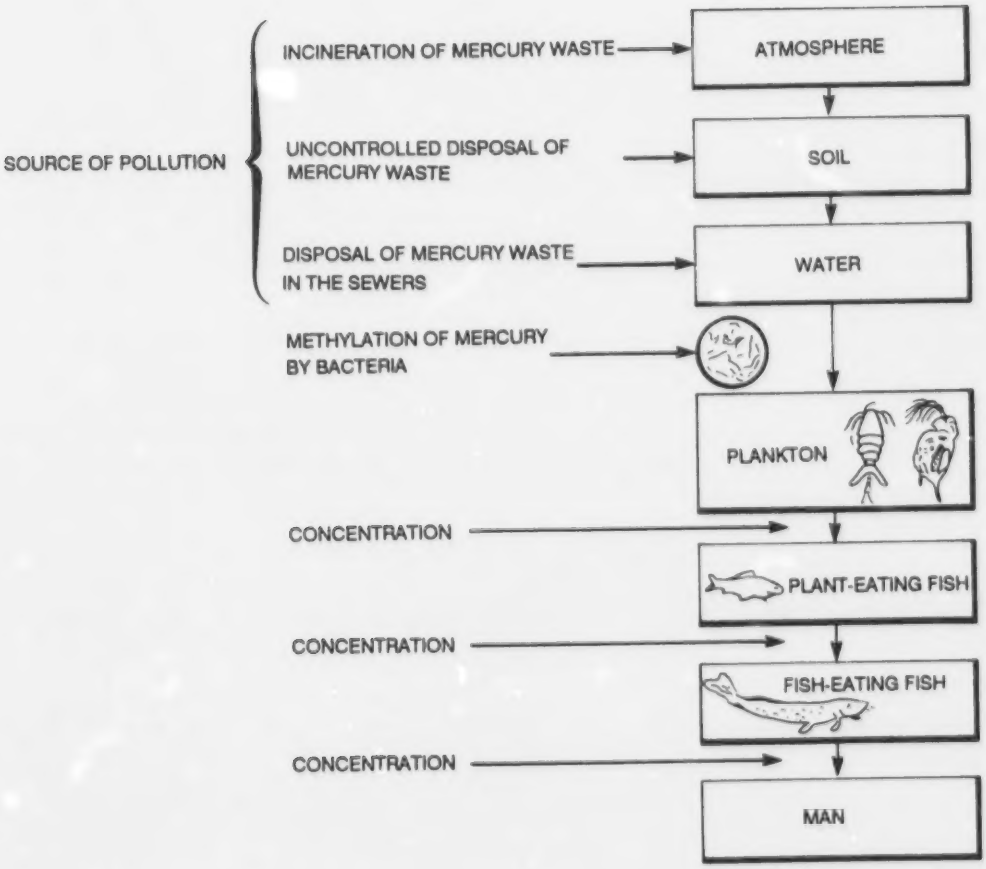


Figure 10 **Environmental Problems Associated with the Disposal of Used Batteries by Household Waste Disposal Networks[56]**

Most industrial secondary cells are recovered, especially in Europe. On the other hand, rechargeable batteries for home consumption are eventually found in the household waste disposal system, much like primary cells. Rechargeable batteries have a long life span, and can be recharged more than 1 000 times; some manufacturers offer a guarantee of five years. Thus, it is difficult to evaluate the environmental repercussions of rechargeable batteries, since only a small percentage has entered the waste stream.

Table 22 shows the average concentrations of cadmium typically found in household waste.

Of the 50 tonnes of cadmium contained in household waste in the Netherlands, 90% is found in sanitary landfill sites.[8] Cadmium from used rechargeable batteries is released only after a considerable period of time. Under anaerobic conditions, the cadmium becomes closely bonded with organic matter and migrates slowly. The adsorption of cadmium into the soil considerably reduces the concentration of cadmium in the leachate.[8]

If the sanitary landfill site is not lined with a watertight membrane, the cadmium contained in the leachate will percolate through to the underlying groundwater, and eventually leave the landfill site.

Contrary to mercury, which vaporizes rapidly during incineration, cadmium remains in a particulate state and can be retrieved from the residual and fly-ash retained by mask or electrostatic filters. Only about 3% of the cadmium escapes. Consequently, the concentration of cadmium in incinerator residues is becoming increasingly high. The wisdom of burying this waste without preliminary processing is being questioned. In many situations, the concentrations of cadmium in the combustion ash will exceed the maximum allowable values.

In the Netherlands, cadmium emission from landfill sites is not considered as an environmental hazard.[8] Dutch authorities, however, encourage the collection of rechargeable batteries.

Table 22 Concentrations of Cadmium Contained in Some Types of Waste

Type	Concentration of cadmium (ng/kg)
Textiles	6
Plastics	75
Non-ferrous	<500
Leathers, rubber	
Linoleum	33
Paper/cardboard	<1
Rechargeable batteries	150 000 000 000

Source: 8

Section 6

Experiences in Other Countries

6.1 Multilateral Measures and Legislation

The problems surrounding the disposal of used primary and secondary cells are of predominant interest to the countries of the European Economic Committee (EEC).[57] The EEC has prepared a proposal containing directives and measures aimed at protecting the environment from hazardous materials contained in primary and secondary cells. As a result of this directive, a progressive reduction in the mercury content of alkaline batteries is underway in various European countries.

European Economic Committee member countries, including Switzerland, have unanimously adopted the proposed measures. The directive contains several sections dealing with the labelling, collection, and disposal of primary and secondary cells.[37] There are sections recommending the use of batteries with low mercury contents, and limiting the mercury content of batteries to an identical value in all member countries, so that trade is not affected; other sections deal with the labelling of batteries. The countries involved have also asked battery manufacturers and importers to take strong measures to lower the rate of mercury in alkaline batteries by 1990.

The directive proposed that manufacturers and importers pay disposal tax and import duties to cover disposal costs.[37] The directive also states that the mercury content of alkaline batteries must be limited to 0.15% of the total battery weight by 1990.[21]

Even though they are convinced that no real environmental risks are involved, members of the European Battery Manufacturers Association, (Europile) agreed to adopt the most recent technology, which will make it possible to considerably reduce the mercury content in alkaline batteries by 1990. Four reduction steps have been imposed on the manufacturers by 1993: 0.50% in weight of Hg until 87-01-01; 0.30% in weight of Hg until 89-01-01; 0.15% in weight of Hg until 91-01-01; and 0.10% in weight of Hg until 93-01-01.[37]

In other words, the mercury content of alkaline batteries will be reduced by 85% by 1990. It is important to note that present technology does not allow the additional reduction in the mercury content in alkaline batteries to 0.10%.[37] The costs of these modifications have been estimated at 80 million ECUs (European Currency Unit).[25,21]

Measures aimed at reducing the mercury content of alkaline batteries have been introduced in Japan since 1984. American battery manufacturers also expect to lower the mercury content in alkaline batteries, even though no coercive legislative measures are in place.

In an attempt to ease the consumption of mercury oxide batteries, various countries favour replacement, and encourage the use of zinc-air batteries instead of mercury batteries. Efforts to find substitutes for mercury oxide batteries in other applications have been slowed by the high price of silver oxide batteries, the result of a considerable rise in the price of silver on the marketplace since 1980.[42] The replacement of rechargeable nickel-cadmium batteries is not being contemplated at this time.

The "polluter pay principle" is applied to battery manufacturers and importers in some

countries. The unanimous adoption of measures greatly increases the chance that they will be accepted by battery manufacturers who are more willing to meet the requirements of the decisions made by the government when measures do not differ too much from one country to another.

Switzerland was the first European country to legislate the identity of polluting batteries and measures for their disposal. Since 1986, all the parties involved (battery users, retailers, manufacturers, and importers) have had to return all used batteries that have been identified as contributing to pollution. Section 6.2.2, which deals with the experience of Switzerland, elaborates on these regulations.

Other countries, such as the Netherlands, Sweden, and Denmark, have implemented, or are in the process of implementing the substitution of HgO batteries or the collection of used batteries.

The purpose of a battery identification program is to urge consumers to return labelled batteries to a special waste collection centre, or to a battery retailer, as part of an organized program. In other words, labelling the batteries enables the consumer to know whether a battery must be discarded in a particular way, or if it can be disposed together with household waste.

The labelling system must be adopted internationally if it is to be effective. Many suggestions concerning the labelling of environmentally hazardous batteries have been proposed, especially the use of affixed colour-codes and pictograms. The directives issued by the EEC suggest the battery labelling system must be the same in all member countries, to facilitate collection. For example, all batteries containing more than 2% mercury or cadmium will be appropriately and visibly labelled red. Batteries with mercury or cadmium contents between 0.15% and 2% will be labelled in yellow.[37] (Button batteries are too small to be labelled).

An international program to label mercury oxide button batteries is already in place and has been adopted by the International Energy Commission (IEC). HgO batteries will be identified with an easily understandable symbol of a "+" surrounded by a circle (IEC Standard TC 35).[37] In some countries, the HgO battery package contains an explanatory note that urges consumers to return their used batteries. The adequate identification of environmentally hazardous batteries could increase the rate of collection. In some countries, alkaline and nickel-cadmium rechargeable batteries can be sent to special collection sites, or can be recycled; while carbon-zinc batteries can be discarded together with household waste.

In order to increase the collection rate, various foreign organizations have proposed a deposit system for environmentally hazardous batteries. In such a system, the buyer would pay the retailer a certain amount when the battery is bought, and this sum would then be reimbursed when the battery is returned.[37] Currently, both the manufacturing industry and the retailers are strongly opposed to any kind of deposit on batteries. They feel such a system is cumbersome to implement, and involves high administrative costs for distributors, while making the job of the retailers more difficult.

For these reasons, the battery deposit system was rejected by member countries of the EEC.[37] Existing collection programs depend upon the voluntary participation of the consumers.[58]

6.2 Used Battery Collection Programs in Other Countries

Growing environmental concern about mercury has led government authorities and communities in many countries to implement recovery programs aimed at products containing small quantities of mercury, such as used primary cells and thermometers. The collection and recycling of potentially

hazardous products is common practice in many European countries and in Japan.

In general, the recovery of used batteries meets technological and economic obstacles that limit the effectiveness of organized collection programs. In many cases, these have caused projects to fail after a short period of time.

The collection and recovery of used batteries should not be considered as a lucrative operation, like the collection and recycling of paper, glass, or metal, but as a necessary community service.

Generally, administrative authorities are not willing to absorb the deficits produced by operations that collect and recycle used batteries. In this case, they must settle the accounts with the battery manufacturers and distributors. Authorities in countries interested in implementing programs for the collection of used batteries prefer to negotiate with representatives of the battery industry, rather than legislate. In both cases, battery suppliers will be responsible for the costs of the system.[14]

From this study of various used battery collection programs, it can be concluded that, in general:

- The recovery of silver oxide batteries is profitable. For this reason, it is carried out everywhere, and is normally organized by independent recovery firms;

- The recovery of mercury oxide batteries is not profitable, but could be if the batches of collected batteries also contained silver batteries. However, it is probable that retailers would collect the silver batteries for resale to private recovery firms. Most existing programs are based on the collection of HgO batteries; and

- The collection of alkaline batteries is costly, and their recovery is not profitable because they contain only a small percentage of mercury. Thus, the cost of recycling exceeds the value of the materials recovered.

Retailers generally accept the idea of installing collection boxes or containers in their stores, providing that no collection costs are involved.

A short and simple collection circuit is generally followed, and it can be represented as:

consumer → retailer → collector → recycling plant.

The basic elements of used battery collection programs include:

- public education;

- installation of collection containers;

- the organization of a system to pick up the containers;

- storage; and

- adequate recycling of the collected batteries.[14]

Programs for the collection of used batteries are being developed and launched in Canada and the United States. Generally, these begin with an information campaign that emphasizes the dangers surrounding the uncontrolled disposal of used batteries.

To be successful, the campaign must provide information and organize educational programs that encourage consumers to participate. The information program is generally continued during the entire process, to maintain and increase public interest. The distribution of pamphlets and brochures is the common method of education, followed by circulars addressed to the retailers, stickers with a logo, posters, radio announcements, articles in the written press, conferences, special telephone lines, etc. The program will succeed only if the consumers are made aware that they must return their used

batteries. The education program also informs the public about choices they have between various types of batteries.

In the past, the problem of used batteries was only associated with mercury oxide batteries. According to those responsible for collection programs, it is imperative to prevent these batteries (whose mercury content can be as high as 30% of the total weight) from being incinerated.

The first large-scale programs for the recovery of used mercury oxide batteries started in 1976,[42] and they have become common practice in many European countries. The mercury content of mercury oxide batteries, and their easy storage made it possible to introduce a recycling program that was both technically and economically feasible in 1976. However, the situation has changed due to a drop in the price of mercury on the marketplace, and the diminishing use of mercury oxide batteries. The present economic climate, however, is favourable for the collection of silver oxide batteries; collection programs can be easily profitable.

The Europile Association has taken a position respecting the participation of manufacturers in the used battery collection program, even though it has stated that it sees no real problem with the disposal of used batteries. Negotiations respecting the imposed restrictions have been undertaken with government authorities in various countries. The restrictions in Switzerland are the most stringent. In an effort to curb environmentally hazardous mercury, manufacturers recently disclosed their intention to encourage the use of zinc-air batteries instead of mercury batteries in hearing aids.

The mercury content of alkaline batteries represents a much greater threat to the environment than the mercury content of mercury oxide batteries. For this reason, alkaline batteries are collected in some countries. These programs generally include rechargeable nickel-cadmium batteries.

Foreign collection programs aimed at cylindrical batteries (alkaline batteries, Ni-Cd batteries, etc.) are listed in Table 24.

As soon as their energy has been depleted, rechargeable Ni-Cd batteries are discarded into the household waste, thereby increasing the cadmium content of this waste. According to a study done by the OFPE (Federal Environmental Protection Office, Switzerland), rechargeable nickel-cadmium batteries are similar to mercury batteries from an environmental point of view.[59]

In Europe, almost all industrial Ni-Cd secondary cells are recovered, although their consumption is small in comparison with that of rechargeable batteries.[37] Generally, these secondary cells are collected by the manufacturers and sent to a recycling or controlled disposal centre. The cathode is sold for its nickel content, and the anode for its cadmium content.

The anodes of used nickel-cadmium secondary cells are sent to only two cadmium recycling centres in Western Europe; namely SNAM (National Metal Refining Corporation) in France, and the Sab Nife Corporation, in Sweden.[18] The cadmium-recycling plants are mainly interested in the nickel used in secondary cells.[18]

The quantity of cadmium contained in used secondary cells in member countries of the EEC was estimated to be 1 000 tonnes in 1990, and is expected to increase by 5% per year, which would represent 1 850 tonnes of cadmium by the year 2000.[18]

The rate of collection is generally defined as follows[41]:

$$\frac{\textit{Quantity of batteries collected in one year}}{\textit{Quantity of batteries consumed the pevious year}} \times 100$$

The results of a program for the collection of used batteries depend upon three essential factors:

- the existence of a network for the collection of used batteries;
- public education; and
- the education of the retailers.

The rate of collection of mercury button batteries varies between 30% and 80%. Switzerland has the highest collection rate, with about 80% of HgO batteries recovered in 1984[60] (see Table 23).

6.2.1 Industrial Recycling of Collected Batteries

The recycling of used batteries involves the processing and reutilization of the secondary materials contained in these batteries.[37] In foreign countries, there are few installations for the recycling of used batteries (Tables 24, 25). Most of the batteries collected are generally discarded in controlled sites.

The most important requirements for the environmental and economic success of a battery recycling plant, apart from the necessary technology, are the legal clauses or stipulations concerning battery disposal and the need of a constant supply of used batteries.[40] The problems involved in the recovery of batteries include insufficient control over battery supply and resale price of the materials recovered.

The main objectives of a recovery plant for used batteries are the adequate recycling of the mercury and cadmium, and an examination of the economic feasibility of extracting other metals contained in the batteries.[18]

The non-toxic marketable metals contained in large quantities in batteries include iron, zinc, and manganese (Table 26). Since batteries are made of several metals, they require expensive and complex processing for successful extraction of the recyclable elements.[37] The recovery of mercury and cadmium, like that of lead, often involves the risk of pollution. Consequently, the installations must meet strict environmental standards when mercury and cadmium are involved.

The best method of processing button batteries is to recycle them. They are initially crushed in order to extract the mercury by evaporation and recondensation (distillation). The recovered metal can then be used as a raw material. The process of recycling

Table 23 Collection Rate of Mercury Oxide Batteries in Some Countries

Country	Rate of collection		Year
	HgO batteries (%)	Other types (%)	
Switzerland	80		1987
Denmark	40-65		1982
Sweden	50		1982
Western Germany	41		1983
United Kingdom	33		1983
The Netherlands	30	3[1]	1986
Japan	27	9[2]	1986

Sources: 41, 42, and 61

1 Southern provinces
2 Button batteries of all kinds

Table 24 Installations that Recycle Used Batteries in Other Countries

Country	Recycling of HgO batteries	Recycling of Ag_2O batteries	Recycling of alkaline and other batteries	Recycling of Ni-Cd rechargeable batteries
Switzerland			o	
France	x			
Sweden			o	x
Western Germany			o	
Austria			x	
The Netherlands			o	
United Kingdom		x		
Belgium				o
United States	x			
Japan			x	
Canada			o	

x existing installations
o planned installations

Various conditions must be met before the battery recycling system is profitable. Among the most important factors are:

- a constant supply of batteries for recycling;
- a high concentration of materials to be recovered;
- efficient technology;
- the re-utilization of secondary materials; and
- an acceptable price for the recovered materials.

mercury button batteries takes about 24 hours, and the mercury is generally chemically purified by distillation to obtain a product that is 99.9% pure.

Silver oxide batteries undergo the same treatment as mercury cells, but an additional stage makes the recovery of silver oxide possible. The silver oxide is then processed into silver, and reused as a raw material.

The best method of recycling alkaline batteries is to separate the pollutants, re-use the suitable components, solidify the residues, and finally, dispose of the waste.[59]

The collected batteries are sorted into three groups: recyclable materials, materials that can be incinerated, and waste that can be discarded. Generally, sorting is carried out manually, and is facilitated by the labelling of mercury oxide button batteries. It is essential that mercury oxide batteries are separated from ordinary batteries, in order for recycling to be profitable.

An effective process to sort collected batteries has yet to be developed. The most promising results are from an x-ray identification technique.[18] The Technology Branch of the Netherlands Organization for Applied Scientific Research (TNO) has tested various procedures for recycling various small batteries at the same time.

It is necessary to sort the batteries when the proportion of rechargeable nickel-cadmium batteries exceeds 1%. The reason is that the presence of nickel-cadmium batteries interferes with the recovery of mercury batteries (cadmium is a contaminant of mercury). The recovery of cylindrical

Table 25 Used Battery Collection Programs in Other Countries

Country	Existing HgO battery collection program	Existing alkaline battery collection program	Existing or planned legislative measures	Existing or planned recycling plant
Switzerland	x	x	x	x[5]
Denmark	x	x	x[1]	
Sweden	x			x[6]
Western Germany	x	x[2]		
United Kingdom	x			
The Netherlands	x	x	x[4]	x[5]
Austria	x	x	x	
Belgium	x			
France	x			x[6]
Italy	x[2]	x[2]	x[3]	
Japan	x	x	x[5]	
United States	x[7]	x[8]		x[9]
Canada	x[10]	x[11]		x[12]

[1]Legislative measures planned for the near future
[2]Regional collection
[3]"Reggio Emilia" municipal legislative measures
[4]Code of behaviour
[5]Recycling dry cells only (alkaline and carbon-zinc batteries, etc.)
[6]Recycling nickel-cadmium rechargeable
[7]Organized collection in the City of New York
[8]Organized collection in the counties of Windsor, VT and Sullivan, NH
[9]Mercury Refining Ltd., Albany, NY (mercury and silver)
[10]Toronto, by the Toronto Recycling Action Committee (TRAC)
[11]Toronto, by the Toronto Recycling Action Committee (TRAC)
[12]Hevmett Recovery Ltd., Port Colborne, Ont. (Voest-Alpine process)

Table 26 Percentages of Metals Contained in Domestic Primary and Secondary Cells

Type of battery	Pb	Ni	Cd	Zn	Mn	Ag	Hg
Lead secondary cell	65						
Ni-Cd secondary cell		20	15				
Zn/MnO_2 acid				15	30		0.01
alkaline				15	25		0.5-1
$Zn-Ag_2O$				10		30	1
Zn-HgO				10			30
$Zn-O_2$				10			1

Source: 22

batteries is an expensive process when the batteries include nickel-cadmium rechargeable cells. These batteries must be carefully separated and sent to a special installation for the recovery of the cadmium. The major obstacle to the recycling of nickel-cadmium rechargeable batteries is the lack of a universal identification system of labelling the batteries.[18] The effect of the presence of lithium batteries is still unknown.[23]

Under no circumstances should mercury batteries be present in the lot of nickel-cadmium batteries to be recycled. The presence of 1% of mercury may cause great difficulties and considerably increase the cost of recycling.[37]

Even though the technology to recover batteries exists, its profit-making capacity remains controversial.[22] In fact, this operation is only profitable when the value of the metals is sufficiently high. Thus, the limited quantities of these materials, their low price, and the multitude of materials contained in the used batteries remain as obstacles to the development of new recycling installations.

Considering the small quantity of mercury present in the batches to be processed, it is impossible to recycle carbon-zinc and alkaline batteries with good economic results.

The factors that affect the installation of new recycling plants include:

- the decreasing content of mercury in alkaline batteries in some countries that have imposed restrictions on manufacturers and importers;
- the low value of other materials contained in the batteries;
- the need to use advanced and expensive processes to separate and purify materials of little value, and whose composition may constantly vary as a function of new techniques (for example, the introduction of indium);
- the decreasing value of mercury, and rising energy costs;
- the implementation of stringent safety measures that make it difficult to recycle mercury batteries profitably; and
- the increasing presence of zinc-air and lithium batteries in the batches to be recycled.

The following sections describe the programs used for the collection of used batteries in various countries.

6.2.2 Switzerland

Switzerland is frequently cited as a good example of environmental protection, and of the recycling of household waste. This country was the first to propose a program for the collection of used batteries. In fact, for several years, electric batteries have been treated as a special waste category that is selectively collected and appropriately eliminated (recycling or controlled elimination).

The Swiss firm Leclanché Inc. is a large battery manufacturer, and in 1971 it was the first to implement a program for the collection and recovery of used batteries. The program was only for mercury oxide cells[62] and depended on the consumer returning the used batteries through instructions appropriately labelled on the battery package. For the last few years, this Swiss firm has requested that used mercury and alkaline batteries be returned to their Yverdon plant, or one of the 13 warehouses provided by the company.[63] The Toxic Branch of the Federal Public Health Office launched the first official program for the collection of mercury oxide batteries. After the Swiss Environmental Protection Act came into force, all these activities were taken over by the OFPE. All manufacturers, importers, and distributors of batteries were asked to participate in the program and assume the costs of publicity.[63] The design and cost of public education and collection containers

were shared by all the manufacturers. The system for collecting used batteries in Switzerland is partially the responsibility of industry (retailers, producers, and importers of batteries), in accordance with the "polluter must pay" principle.

Districts are responsible for advertising campaigns that encourage the return of used alkaline and button batteries to special containers in selected stores. The Swiss army takes its used batteries (about 200 t/yr) to landfill sites that are located in other countries.[10]

Switzerland has the highest rate of recovery of mercury oxide batteries; its program is over 80% effective (Table 27).[61] Initially, mercury oxide batteries were sent to a recycling installation owned by the German company Dégussa (Elwenn & Frankenbach Gmbh) in Frankfurt.[64] However, as a result of the phasing out of the mercury-related activities of this company in June 1987,[65] HgO batteries are now stored, then sent to special disposal sites in Spain (Almadén mines) and Eastern Germany.

Since 1982, Switzerland has dealt with the problem of alkaline batteries, which are responsible for ten times more mercury in waste than that due to mercury oxide batteries.[64] The Zurich and Lausanne regions were the first to collect cylindrical alkaline and other types of batteries. In the Swiss Collection program, all types of used batteries can be returned to the point of sale. This facilitates the task of the consumer.

The Swiss legislation is the most stringent in dealing with domestic batteries.[10] The use of mercury is strictly regulated. The provisions made by the authorities form part of a series of measures aimed at reducing environmental pollution by mercury and cadmium. The objective is to reduce the quantity of mercury in household waste to one tonne.[10] Hazardous batteries are differentiated from those that are less polluting. Authorities consider batteries to be polluting or highly hazardous when their mercury or cadmium contents exceed a total of 250 mg per kg of batteries.[66] Since September 1987, following the adoption of new legislation, all batteries containing more than 250 g of mercury or cadmium per kg of batteries cannot be imported into Switzerland or produced by a manufacturer. Disposable battery-operated objects were to be sold in the country only until 31 August 1988.

The battery regulations require the cooperation of manufacturers and importers, retailers and consumers. The new law urges the manufacturers and importers to reduce the quantities of mercury and cadmium contained in the batteries, to identify clearly those batteries that have mercury or cadmium contents above the recommended values, and to collect and properly dispose of batteries that do not meet the requirements of the regulations.[25] The manufacturers and importers must recycle or dispose of their products and those of others;[10] they are also expected to disclose the quantities of batteries produced or imported, as well as their cadmium and mercury contents.[67]

Table 27 Rate of Recovery of Mercury Oxide Batteries in Switzerland

Year	Rate of recovery (%)	Quantity of recovered HgO batteries (tonnes)	Rate of collection of other types of batteries (%)
1975		1.8	
1983	80	9.6 (E42)~	25-30

At the manufacturing or importing stage, the OFPE has planned to collect a tax per tonne of batteries to cover the cost of recycling the used batteries.[67] This means that the consumer will pay an additional 3 to 5 centimes more for each battery purchased.[10]

The OFPE's ODS - (Regulations Respecting the Transportation of Hazardous Substances), which came into force in 1986, includes a clause dealing with batteries containing mercury and cadmium. The clause establishes a distinction between batteries according to the degree of danger involved; it also requires the dealers to accept used batteries, and the consumers to return them (Figure 11).

The ODS Appendix contains a requirement for the use of pictogram labels to identify polluting batteries (Figure 12). The label must indicate that the product should not be discarded in a wastebasket, but taken to an appropriate recycling centre.[68] The proposed pictogram must appear on polluting button batteries. Swiss consumers are required to take used batteries showing this pictogram to either a selective collection centre,[67] a point of sale, or a station for the collection of toxic materials. Since 31 August 1987, it has been forbidden to import into Switzerland any of the hazardous batteries that do not carry the required pictogram.[28]

Battery manufacturers and dealers are required to accept all used batteries free of charge. Recommendations are also made to retailers to sort their batteries into three categories: button batteries, nickel-cadmium rechargeable batteries, and others.

Manufacturers that do not recycle used batteries must dispose of them in accordance with the provisions respecting hazardous waste.[69] Manufacturers of disposable battery-operated objects must use non-polluting batteries.[67] Retailers of batteries or battery-equipped objects must visibly display a notice describing their participation in this program, in order to encourage consumers of hazardous batteries to return them.

The mercury content of alkaline batteries must not exceed what can be handled by available technology. The limit of mercury is expressed in g/kg of zinc; a limit of 20 g was initially set on 1 January 1988, and was lowered to 10 g on 1 January 1990.[66]

The dealers, producers and importers of hazardous batteries dispose of them in accordance with the technical provisions of the Confederation. They must notify the OFPE regarding the quantities of batteries, and their proportions of cadmium and mercury.[66] Legislation which has been in force since April 1987, requires the sender to notify the OFPE in writing before any used batteries are exported.[70] Businesses that recycle, discard, or export polluting batteries are required to submit to the OFPE an annual report of the quantities of batteries handled.[67]

Large battery distributors generally provide containers for the collection of used batteries. Since 1982, the large Swiss cooperative Migros has annually distributed over 100 000 cardboard collection containers in two sizes (for button and other types of batteries). The cooperative sells nearly 20 million batteries annually, which represents one fourth of the total battery consumption in Switzerland. The collection boxes are generally installed in strategic locations in the company's branch stores. The Migros system can be summarized as: consumer → Migro retailer → provisional storage centre → battery exporting firm → foreign country (Eastern Germany, France, Spain).[58] Of the 1 800 tonnes of batteries sold by the cooperative in 1987, 400 tonnes were returned by the consumers.[71]

Until 1985, some of the recovered carbon-zinc and alkaline batteries were discarded in the Kolliken site in the Argovie district,[53] which is now closed. Since the closure, cylindrical batteries (carbon-zinc and alkaline batteries) have been exported to

BATTERIES: Table of Measures Imposed by Swiss Regulations Respecting the Transportation of Hazardous Substances

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Non-Polluting Batteries

all batteries containing less than
250 mg Hg and/or Cd per kg of batteries

Polluting Batteries

manganese-zinc dioxide batteries
containing more than 250 mg Hg and/or
Cd per kg of batteries

manganese-zinc dioxide alkaline batteries
containing

- more than 20 g Hg per kg of zinc
  (about 3 g Hg per kg of batteries)
- between 10 and 20 g Hg per kg of
  zinc
- under 10 g Hg per kg of zinc
  (about 1.5 g Hg per kg of batteries)
  and more than 250 mg Hg per kg of
  batteries

other batteries
(for example, mercury batteries or
nickel-cadmium rechargeable batteries)

Disposable objects equipped with polluting batteries
(for example, disposable watches).

Figure 11 Measures Imposed by Swiss Regulations Respecting the Transportation of Hazardous Substances[67]

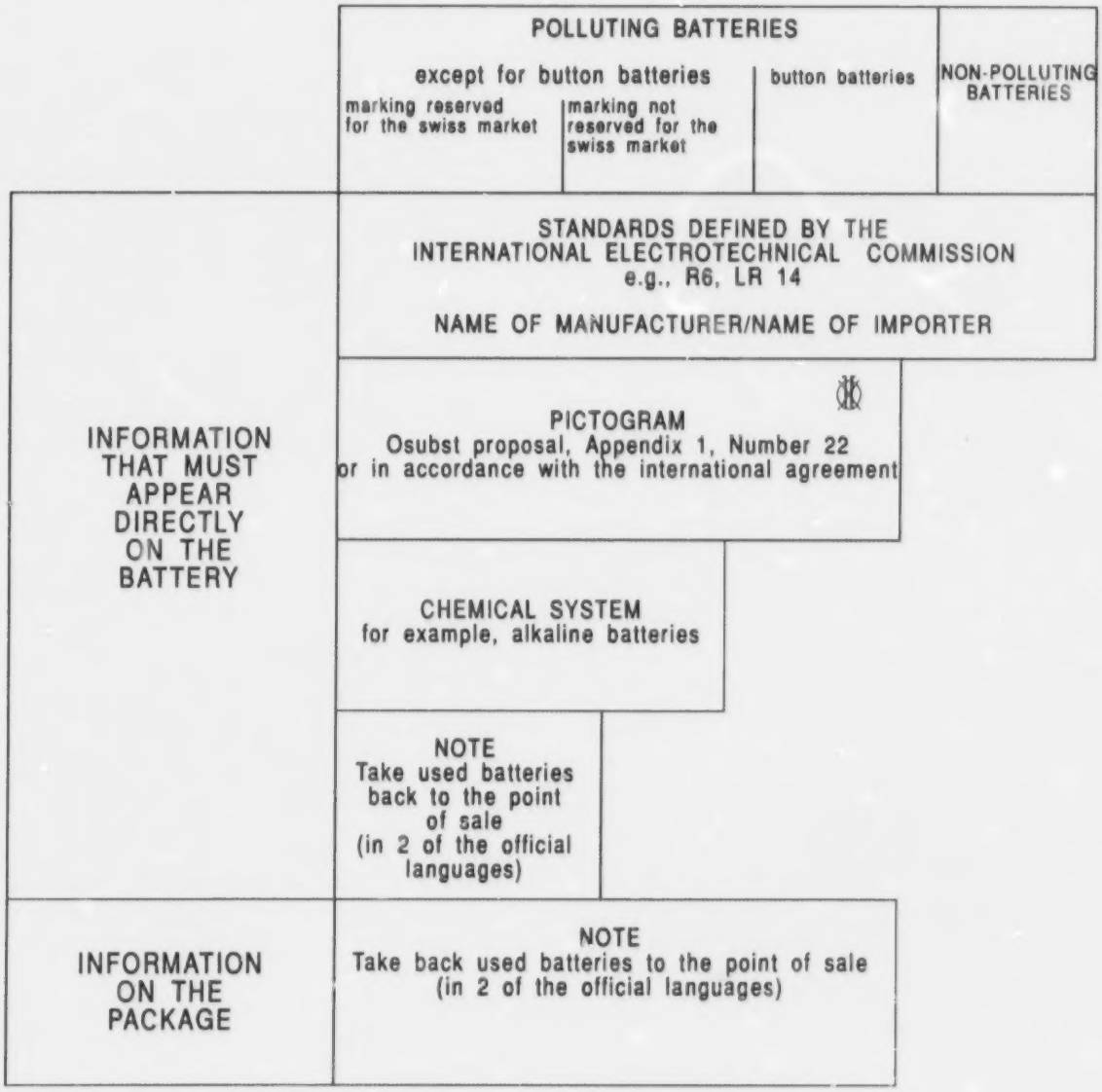

POLLUTING BATTERIES
except for button batteries
marking reserved for the swiss market
marking not reserved for the swiss market
button batteries
NON-POLLUTING BATTERIES
INFORMATION THAT MUST APPEAR DIRECTLY ON THE BATTERY
STANDARDS DEFINED BY THE INTERNATIONAL ELECTROTECHNICAL COMMISSION
e.g., R6, LR 14
NAME OF MANUFACTURER/NAME OF IMPORTER
PICTOGRAM
Osubst proposal, Appendix 1, Number 22
or in accordance with the international agreement
CHEMICAL SYSTEM
for example, alkaline batteries
NOTE
Take used batteries back to the point of sale
(in 2 of the official languages)
INFORMATION ON THE PACKAGE
NOTE
Take back used batteries to the point of sale
(in 2 of the official languages)

Figure 12 Battery Labels Used in Switzerland

controlled disposal centres in France and Eastern Germany.

Rechargeable nickel-cadmium batteries are sent to the SNAM cadmium recycling installation in France, or are disposed of in Eastern Germany.

Temporary storage and exporting are the only methods used to dispose of used batteries. Since Switzerland does not have any means to dispose of alkaline batteries, and does not have any installations to recycle used batteries, the OFPE ordered in 1986, the development of a physio-chemical method to recycle dry used batteries (carbon-zinc and alkaline batteries).[72] The cost was 500 000 Swiss francs. The development of this process, planned by OFPE and the Migros cooperative, was entrusted to three engineering firms in the Zurich region (EIC, ORFA Umweltechnik AG, and AFIF, which is affiliated with the École Polytechnique Fédérale de Zurich - ETZ).[73] The three firms have developed a patented recycling method that has been installed in a laboratory (Figure 13).

This process can be effectively used to recover mercury and other materials, mainly from alkaline and carbon-zinc batteries. The process involves these stages:

- mechanical crushing of unsorted used batteries;
- separation of coarse and fine particles by washing and screening;
- extraction of paper/plastics from the coarse particles using a density separator;
- magnetic separation of the coarse particles into ferrous and non-ferrous (zinc, copper) metals;
- washing the fine particles with water to extract soluble compounds;
- thermal treatment of the fine particles to recover the mercury; and
- separation of the manganese and zinc compounds from the residue.

Recycling one tonne of batteries rich in raw materials should provide about 270 kg of manganese dioxide, 210 kg of iron, 160 kg of zinc, 20 kg of copper, and 2 kg of mercury.[74] The pilot plant, which was finished in 1988, was projected to recycle about 500 tonnes of batteries per year.[72,75] It was constructed on the site of the Zurich municipal incinerator.[72] A final plant was scheduled to be put into service by 1989-1990; the recycling capacity is about 20 tonnes of batteries daily.[10]

The research carried out at the time of this study indicate that selling recycled products (zinc and manganese compounds) on the recovery market would be very difficult. Installing a battery recycling plant may not be a profitable undertaking. For this reason, Switzerland is considering the possibility of financing the process through a disposal tax that would be collected directly from battery importers or manufacturers (Figure 14). This tax should make it possible to cover all recycling costs, including recovery and transportation.[76]

Another Swiss firm, Recytec Inc. of Morges, owns a process that was patented in September 1987 (the process was developed by Deco-Hanulik). A pilot processing installation in Geneva recycled 200 kg/d of unsorted used batteries, including nickel-cadmium rechargeable batteries. The goal of recycling one t/d of batteries should be reached shortly, but the optimal quantity of batteries to be recycled remains to be evaluated.[77]

6.2.3 The Netherlands

Authorities in the Netherlands are paying particular attention to the disposal of small quantities of hazardous wastes, which have been estimated at 100 000 t/yr, and which, for the most part, remain uncollected.[41] Over 21 domestic products are included in the list of small quantities of hazardous wastes, and electric batteries are listed ninth.

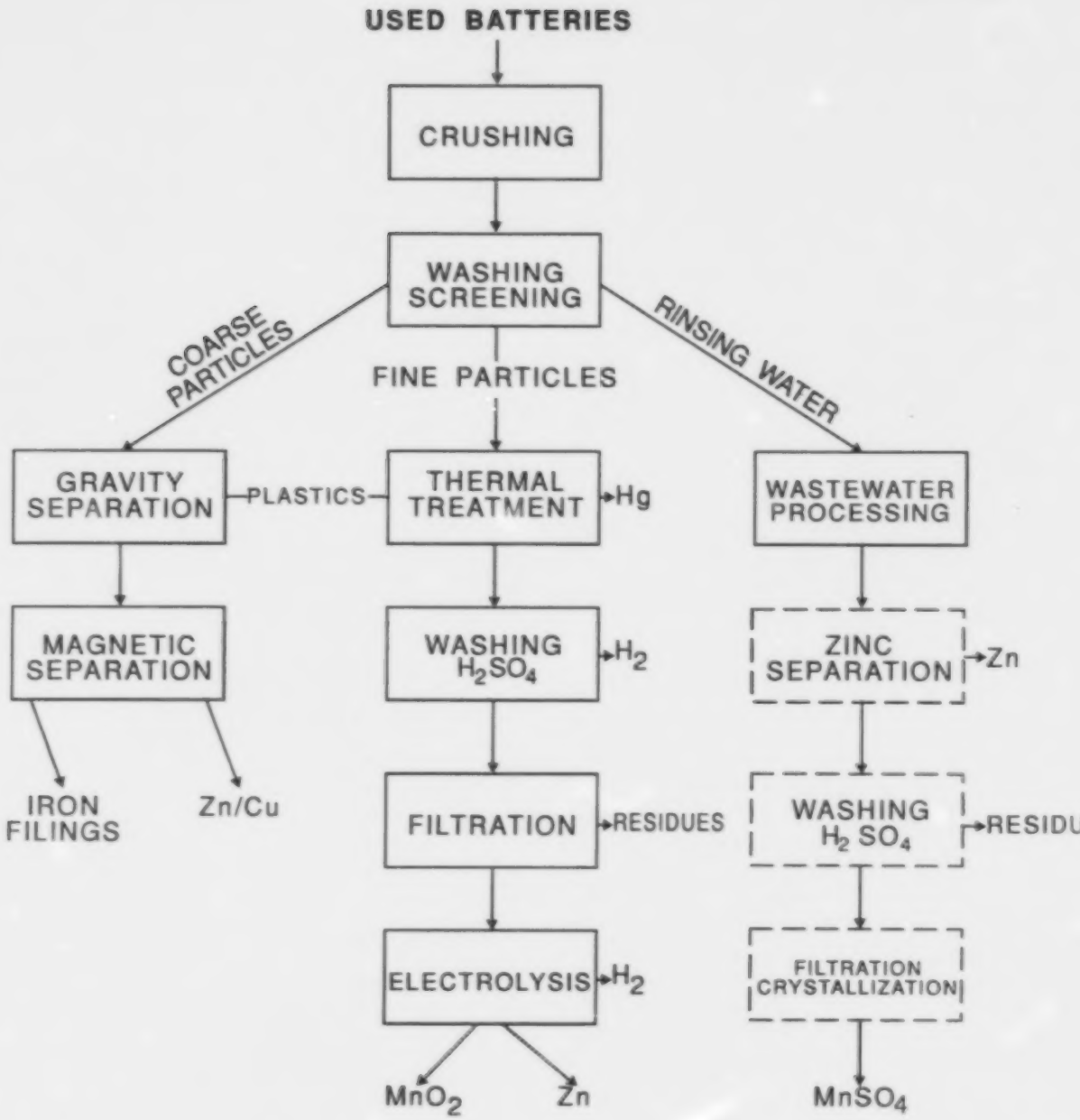


Figure 13 **Operation of the Recycling Process Employed by the Used Dry Cell Pilot Plant Planned for Zurich[74]**

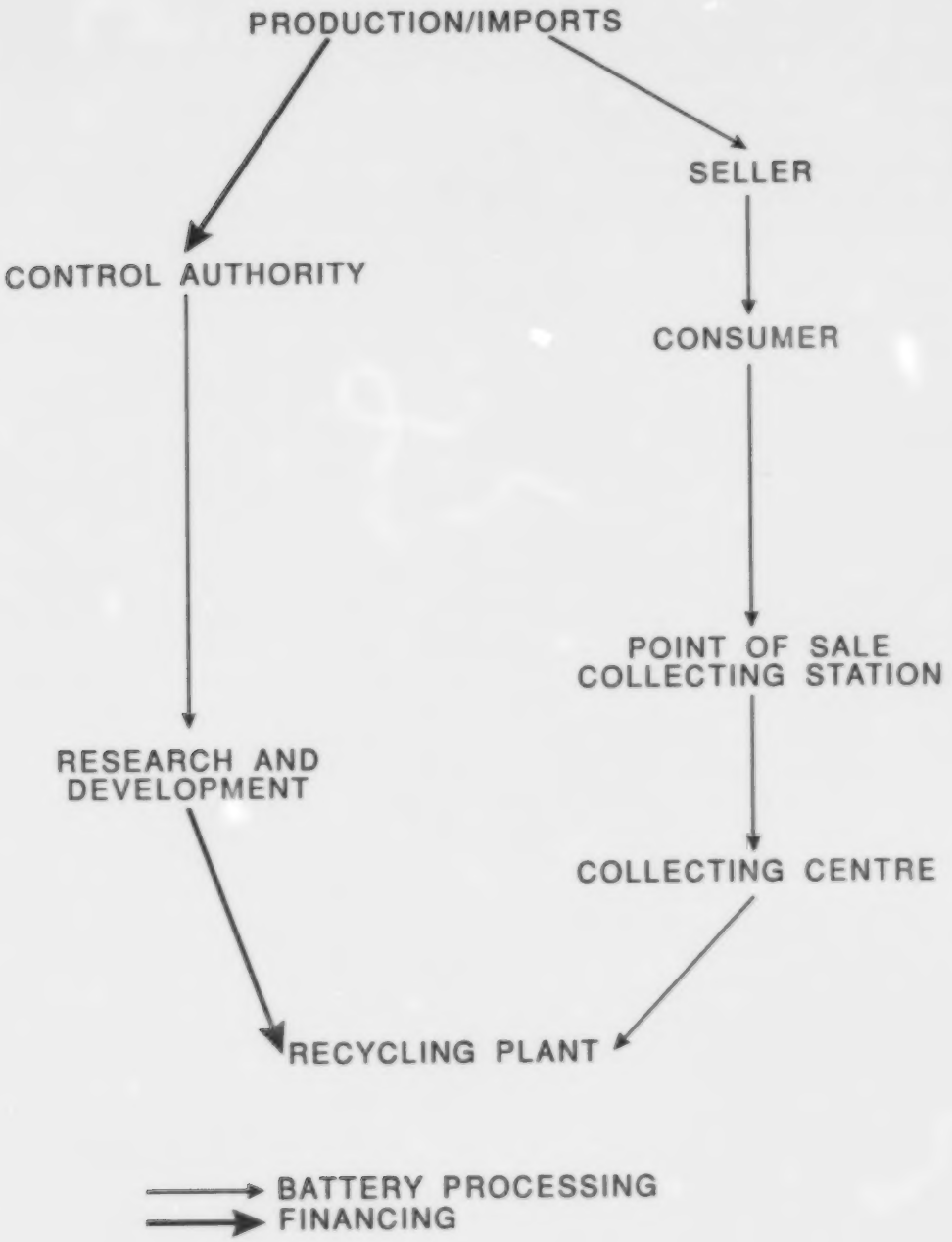


Figure 14 **Financing Through the Use of a Preliminary Tax**
Source: Eutrotech Inc.

According to the Department of Habitat, Land Improvement and the Environment (VROM), since mercury and cadmium are blacklisted substances[51], the presence of heavy metals in batteries means that used batteries have to be collected and discarded appropriately. Zinc is included in the "grey" list.[41] One of the objectives of the "Small Quantities of Chemical Waste" project undertaken by the VROM is to define the characteristics of an effective method to collect the small quantities of hazardous wastes.

In the Netherlands, mercury button batteries have been collected for several years, and the rate of recovery reached 30% in 1986.[41] Since 1985, the VROM has used a Code of Practice to achieve these goals, by working within the framework of a used battery collection program.[78] For example, the Code of Practice urges battery manufacturers to encourage the use of zinc-air batteries for hearing aids.[37] In the next five years, this replacement program will encourage all users to choose zinc-air batteries for hearing aids, and discourage their use for other applications. A new Code of Practice dealing with alkaline batteries suggests reducing their mercury content to levels proposed by the EEC and Europile (from 1% to 0.15% Hg by 1990 for alkaline batteries).[78]

The increasing consumption of rechargeable nickel-cadmium batteries has also been considered by VROM. It is estimated that between 20 and 30% (35-50 tonnes) of the total quantity of cadmium released into the environment is from nickel-cadmium batteries (taking into account the restrictions imposed on other utilization sectors).[79,80]

Since 1984, with the collaboration of NEFIBAT (an association of battery manufacturers) and Battrex (a large distributor of electric batteries in the Netherlands), VROM has tested a system for the collection of used batteries in the southern provinces (where two large cities are located, The Hague and Rotterdam). Government subsidies help the Battrex Company to collect used batteries through its distribution network. Over 800 collection containers designed in the colours of the company (Figure 15) were placed in 700 strategic locations (retail outlets and public buildings).[41] The company collects used batteries by picking up the full containers during each routine delivery. The batteries are subsequently accumulated in the storage facilities of the company (Delft), and eventually discarded or recycled in other countries. Since there is no used battery recycling plant in the Netherlands, and because mercury batteries can no longer be recycled at the Elwenn & Frankenbach Gmbh (Frankfurt) plant, Battrex has had to deal with various storage problems. Rechargeable nickel-cadmium batteries are sent to the SNAM recycling plant in France. Other types of batteries are discarded in controlled sites in West Germany,[78] since there are no operational installations in Europe. The cost of recycling used batteries is high, and varies in accordance with the method of collection.[80]

The experimental battery collection program has a rate of recovery estimated at 3% in 1986, and was projected to reach 33% after more publicity.[41] It is important to point out that the benefits realized by the Battrex company are non-quantifiable, and therefore difficult to evaluate.

There are various independent used battery collection systems in the Netherlands. Some retailer chains (like those specialized in photography, for example Foto-Quelle) have organized their own selective collection program. The cost of recycling the used batteries is automatically covered by a very small increase in the price of the batteries. The sum of 0.25 Florins is generally paid for each battery returned; this encourages consumer participation.

The Technology Branch of the Netherlands Organization for Applied Scientific Research (TNO) and the Department of Engineering of the University of Twente are working on the development of a chemical method to recycle

Figure 15 The Battrex Container for Collecting Used Batteries (The Netherlands)[80]

used batteries. This research project will cost almost 1 000 000 Fl,[78] and involves the development of a new mechanical sorting technique that extracts mercury and zinc from the used batteries. The future commercial exploitation of the installation and the improvement of the shredding technique has been entrusted to the Swedish firm Leto.[80]

About 55% of the batteries used in the Netherlands are carbon-zinc, 26% are alkaline batteries, 2% are HgO batteries, 2% are Ag_2O batteries (1985), and of the rest (15%), 75% are rechargeable Ni-Cd batteries.[41]

The TNO is testing a method for recycling mixed batteries containing between 1% and 2% nickel-cadmium rechargeable batteries. The batteries have to be sorted before recycling, and the rechargeable nickel-cadmium batteries will be subsequently recycled in France or Sweden.

The method proposed by the Netherlands consists of crushing the batteries (alkaline and carbon-zinc batteries) and separating the fine particles (containing carbon, zinc, mercury, and manganese) from the coarse particles. The mercury is then separated from the fine particles, and undergoes thermal treatment to

produce a residue with a concentration of 200 mg of mercury per kg.[81] It is also possible to extract mercury from the fine particles using non-thermal methods. Other materials contained in small quantities, such as metallic or burnt compounds, including cardboard, paper, or plastics, can also be recycled.

In view of the effectiveness of the mercury separation and expected investment costs, TNO has decided to propose a method based on the non-thermal separation of mercury. This process consists of crushing the mixture before recycling, and extracting the metal content. The plant planned by VROM would have a recycling capacity of 5 000 t/yr. The cost of this plant, as well as the relatively low price of heavy metals on the marketplace, mean that this is an unacceptable solution at this time.

6.2.4 France

France has recovered mercury oxide button batteries for over 10 years. Though the use of these batteries is decreasing, they still account for a significant quantity of mercury. The annual consumption of HgO batteries in France is about twenty t/yr, which represents seven tonnes of mercury per year[82] (Table 28). Recovery has always been carried out on a national scale, with the participation of specialized retailers.[42]

In 1978, under government authority, ANRED (National Agency for the Recovery and Disposal of Waste) formed the ARPB (Association for the Recovery of Button Batteries), an organization that consists of nine members: ANRED, and eight button battery manufacturers and distributors. This non-profit organization implemented a program to collect button batteries by mail. Retailers received specially designed boxes for the collection of used batteries that are returned by consumers, who are notified about the program through press announcements. Once the boxes are full (about 1 kg), they are sent back at the expense of ARPB.

The collection of button batteries has enabled the recovery and recycling of a few t/yr of mercury batteries. Poor results at the beginning of the operation and the fact that few silver oxide batteries were returned meant that ARPB had high recycling costs. The low silver oxide return rate was due to private contractors buying silver oxide batteries from retailers. Different sorting facilities exist to process and recycle mercury and silver oxide button batteries. The silver batteries are processed and recycled in England by the Johnson Mathey and Engelhard companies.[65]

The rate of recovery (the number of batteries collected in relation to the number of all batteries sold the previous year) amounted to 78% in 1983 (Table 29). Such a high rate was the result of an intensive information campaign launched by ARPB, and the decision of ARPB to defray the cost of transporting the collection boxes. Before that

Table 28 Consumption of Button Batteries in France

Year	% (cm)			Total weight of button batteries in all systems (t)
	HgO batteries	Ag_2O batteries	Others	
1980	45	54	1	36
1981	38	58	4	42
1982	31	64	5	44

Source: 42

Table 29 Rate of Collection of Mercury Oxide Button Batteries in France

Year	HgO Batteries collected (t)	Hg content (t)	Rate of collection private + ARPB %
1979	2.8		17
1980	2.1		11
1981	2.1		9.5
1982	9.1	3.5	40.5
1983	15.7	5.9	78

Source: 42

date, transportation by mail was paid by the retailers. Of the 15.7 tonnes of HgO batteries collected in 1983, six tonnes were recovered by professional recovery companies interested in silver oxide batteries.[42]

After ARPB had been operating for eight years, ANRED was covering over 80% of the costs (recycling, and operation of the Association).[82] The refusal of the other members to consider a more equitable distribution of expenses in order to improve the rate of collection, resulted in the dissolution of ARPB in 1986.[82] Since the dissolution of ARPB, mercury button batteries are in storage, awaiting an industrial recycling solution.[83]

In September 1987, ANRED launched a new campaign for the collection of button batteries, in association with the Department of the Environment and in collaboration with the French Red Cross. (The collection box and publicity sticker are shown in Figs. 16 and 17). This collection program is concerned with recovering mercury and silver oxide batteries. ANRED collaborated with the French Red Cross to give new impetus to battery collection efforts. The benefits obtained from the recycling of silver oxide batteries should finance the recycling of mercury batteries, as well as the costs of collection. Any residual profits will be used by the French Red Cross for humanitarian purposes.[65]

The collected button batteries will be provisionally stored by local Red Cross committees (Figure 18). The recovery company will be chosen on the basis of a call for tenders by ANRED, and will ensure that all collected batteries are processed appropriately. The contractor's duties include:

- picking up the batteries collected by the French Red Cross;
- storing all the batteries collected at the national level;
- sorting the batteries using a screening process (Ag_2O, HgO, Ni-Cd, zinc-air, lithium);
- ensuring the recycling of HgO batteries;
- recovering the price of silver obtained from recycling Ag_2O batteries;
- ensuring the recycling of nickel-cadmium batteries; and
- storing lithium batteries.

If the results are positive, ANRED will recover part of its investment; the financial risks depend on the proportions of silver batteries collected and the prices in the metal market.[82] The objective of the joint ANRED-Red Cross operation is to recover almost seven t/yr of mercury from the

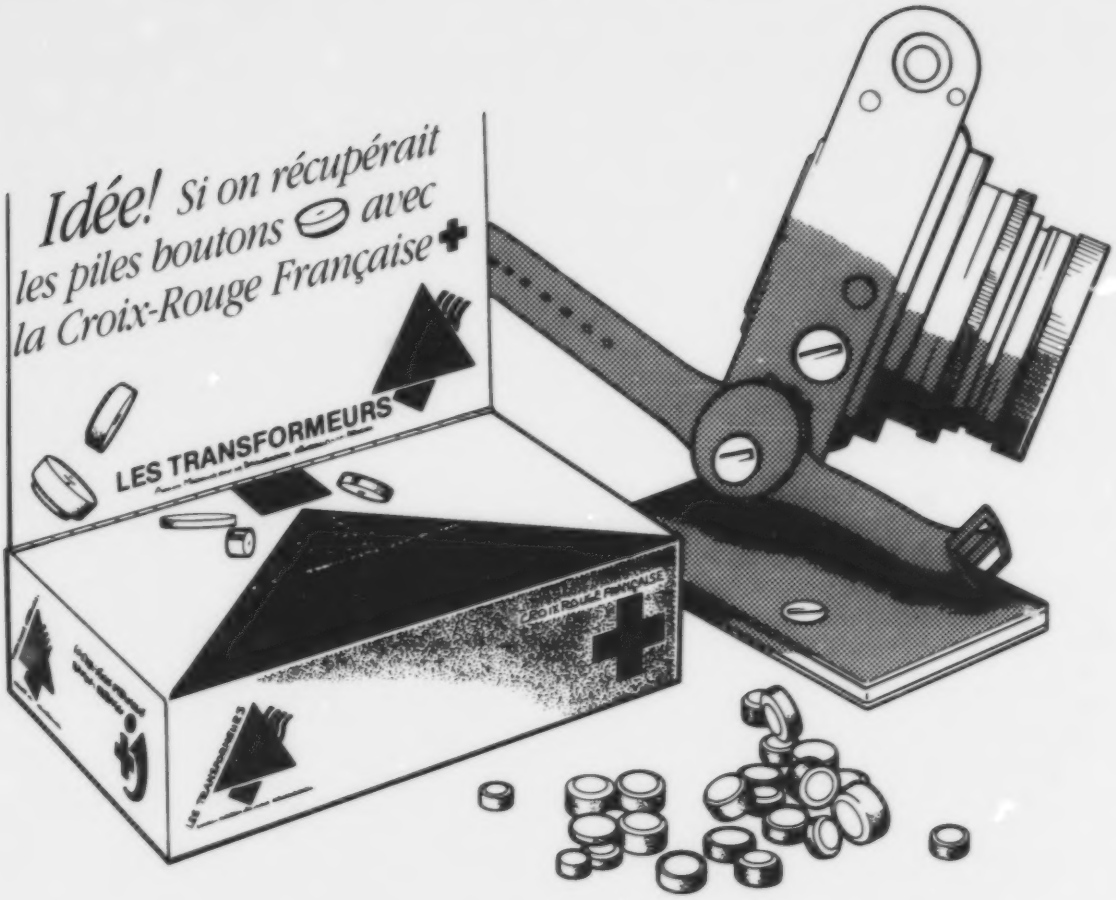


Figure 16 Box for Collecting Button Batteries in France, ANRED-CRF[54]

20 tonnes of mercury button batteries that are consumed annually in France.[56]

The recent cessation of mercury-based activities by the German firm Elwenn & Frankenbach Gmbh has led to disposal problems of mercury batteries throughout Europe. These batteries are not being recycled, but are stored[83] or exported to the Almadén mines in Spain. This situation is not satisfactory, and it is clear that the launching of a nationwide collection program will urge French industrialists to speed up the development of their own projects.[65]

Projects for the creation of centres to recycle mercury waste in France are under consideration.[56] For example, ANRED is working on the creation of a unit to recycle precious metals contained in waste that is produced by the electronics industry.[83] The collected mercury batteries will be sent to the Duclos Environnement installation for recycling.[82] (At the time of this study, mercury recycling installations in France were in a precarious financial situation).

The Duclos Environnement company, which is located near Marseille, operates a mercury recycling facility. The process extracts the mercury under vacuum distillation to prevent leakage into the surrounding environment. In fact, solids, liquids, and gases are treated entirely under vacuum. The types of waste recycled include button batteries, fluorescent tubes, thermometers, dental compounds, waste from the chloride industry, and activated charcoal pellets (Duclos

Figure 17 **The Publicity Sticker of ANRED-CRF[56]**

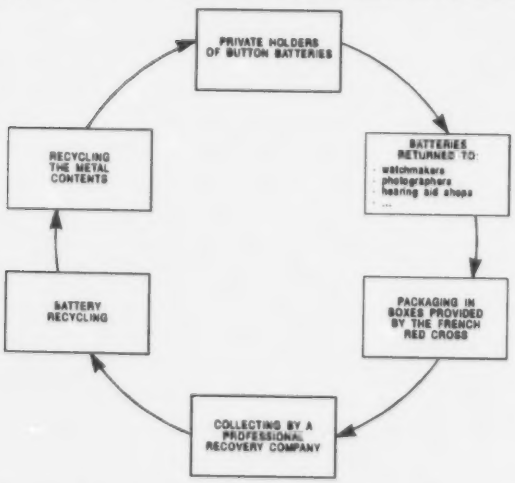


Figure 18 **The Collection System of ANRED-CRF[56]**

Environnement, 1987). The process used to recycle batteries however, requires a preliminary stage that is being developed.

At this time, there is no law requiring the recovery of batteries containing mercury in France. Nevertheless, communities are urged to collect alkaline batteries, even though no program for the recovery of this type of

battery is in place. The efforts of the EEC to reduce the use of mercury have not persuaded the authorities to implement a program for the recovery of these batteries. Rechargeable nickel-cadmium batteries are not recycled, even though there is an installation (SNAM) for this purpose in Lyon. The cadmium used in the SNAM installation is essentially obtained from the manufacturing waste of Ni-Cd rechargeable batteries, and the negative plates of used industrial-type secondary cells that have been returned to the distributors, and whose cadmium content varies between 13% and 25%.[18] SNAM is particularly interested in the recovery valve of nickel (about 25% of the total weight of the secondary cell); this ensures the financial success of the recycling system.

The SNAM processing plant offers an economically profitable process. The plant has been in operation since 1977, and uses the unique SNAM distillation technology. In 1977 the mercury was extracted from silver oxide batteries; however, this activity has been discontinued. The annual recycling capacity of the installation was 700 tonnes of used nickel-cadmium secondary cells in 1986, and was projected to reach 1 000 t/yr in 1987.[37] The eventual expansion of the plant would increase recycling capacity to 2 000 t/yr of used secondary cells.

The recycling activities of SNAM are reputed to be profitable. Recycling costs are however, subject to frequent and significant variations, and depend upon the quantities and nature of the cadmium and ferrous waste that is recycled. The sender assumes transportation costs; they vary according to the distance travelled.[18] The cost of recycling small nickel-cadmium rechargeable batteries is higher because an additional operation (pyrolysis) is required to treat the organic matter. For example, the treatment costs $0.38 US per pound for domestic batteries, and $0.34 US per pound for negative plates of industrial secondary cells.[18] The cadmium produced is at least 99.95% pure; often the purity exceeds 99.99%. The main impurities are nickel, iron, and zinc. SNAM operates mainly as a recycling service. The clients send in used batteries, and a price is charged according to the nature of the materials recycled.

6.2.5 Western Germany

Button batteries have been collected in Western Germany since 1976; other types of batteries since 1982. Primary cells, particularly alkaline batteries, are the source of one half of the mercury emissions produced by municipal incinerators.[23] The quantity of mercury contained in primary cells was estimated at 61 tonnes in 1983, and is mostly attributable to two types of batteries: 56% to alkaline batteries, and 41% to mercury batteries.[42]

Over 75% of the batteries consumed in the Federal Republic of Germany are carbon-zinc batteries (1986). This proportion is tending to decrease in favour of alkaline batteries, whose mercury content is subject to the control measures proposed by the EEC. Mercury batteries are being progressively replaced by silver oxide and zinc-air batteries.[23] The distribution in the use of mercury batteries in 1983 was:

hearing aids: 50%;
photography: 48%;
watches: 1%:
other: 1%.

The rate of recovery of mercury batteries has been constant in the last five years, and is about 40% (Table 30).[23]

Since 1980, German battery manufacturers and importers have made a commitment to provide collection boxes for button batteries to specialized retailers, to collect them by mail (postage paid), and to send them to a recovery centre (for controlled recycling and disposal). The value of the metals recovered pays for the costs of collection.[42]
Ni-Cd button batteries must, however, be separated from other batteries before recycling, when their proportion exceeds 1%.[23]

Table 30 Rate of Recovery of Mercury Oxide Batteries in the Federal Republic of Germany

Year	Mercury content in HgO batteries (t)	Quantity of Hg recovered (t)	Rate of recovery (%)
1981	20.1	9.3	46
1982	25.1	11.3	45
1983	22.9	9.5	41

Sources: 23 and 42

The battery manufacturing industry in Western Germany participates in a national program for the collection and recycling of button batteries.[25] Under the authority of the Federal Environment Agency, battery manufacturers accept without cost to the consumer, their own used primary and secondary cells. These are then discarded in special disposal facilities, together with manufacturing waste, that has been estimated at 500 t/yr.[23] The waste produced by the manufacture of nickel-cadmium secondary cells is recycled outside the country (France); approximately 350 tonnes of metal are recovered annually.[22]

The Waste Disposal Act gives federal authorities the power to require a mandatory deposit and a label for alkaline, mercury, and rechargeable nickel-cadmium batteries.[23] As a result of an agreement reached in 1983 with the Department of the Interior, since 1987, all manufactured or imported mercury button batteries must display a symbol consisting of a "+" surrounded by a circle on the positive terminal. Silver oxide button batteries must display a symbol consisting of a "+". Labelling button batteries facilitates their identification and consequently the process of sorting.[42] The labelling system proposed by the authorities and adopted by the International Energy Commission is being carried out on an international scale.

Apart from the regulations introduced by federal authorities, some communities have their own regulations, and they encourage consumers to deposit used batteries of all kinds in collection containers. Since 1982, these municipalities have proposed the recovery of all types of used batteries through existing collection networks, or by collecting the used batteries in 25, 60 or 100-litre containers that are attached to the receptacles used for the collection of glass. The collected batteries are eventually disposed of in controlled sites in Eastern Germany.[25]

Interest in the recovery of precious metals, notably silver and mercury, prompted the German company Degussa Corporation to recover mercury from button batteries in its affiliate Elwenn & Frankenbach Gmbh, until June 1987.[84] In 1985, 120 tonnes of silver oxide and mercury oxide button batteries were recovered from various countries (Federal Republic of Germany, France, Italy).[85] However, due to the low market value of mercury and the costs of modernizing existing installations to meet new environmental standards, the installations were closed.

Since there is no recovery of the materials contained in these batteries, they are sent to disposal sites in both Western and Eastern Germany. About 5 to 10% of the used batteries are disposed of in Eastern Germany.[23]

At the time of this study, Western Germany was planning to install a plant to recycle used primary cells, but no information was available.[23] The Department of Research and

Technology is financing three research projects to recycle and reduce the mercury content of alkaline batteries. The Varta company, a large European battery manufacturer, is researching the use of a mercury substitute that could reduce the mercury content in alkaline batteries to 1/50th.

6.2.6 Sweden

Sweden has been collecting button batteries for several years, and the rate of collection for mercury oxide batteries has been about 50% (1984).

A national program aimed at collecting all used batteries has been operating since January 1987. Municipalities encourage consumers to place used batteries in special containers that are distributed throughout the country. Mercury batteries and rechargeable nickel-cadmium batteries are sorted, then recycled. Other types of batteries are stored while an adequate recycling method is developed.[47]

Since December 1986, Swedish authorities have implemented regulations that attempt to control mercury and cadmium emissions from used primary and secondary batteries into the environment. Consequently, manufacturers and importers are taking measures to ensure that batteries are less polluting. All battery suppliers are therefore responsible for taking back used batteries, and they must provide information at all points of sale that encourages the consumers to return used batteries. The collected batteries are subsequently sent to a designated site for disposal or recovery.[86]

Manufacturers and importers must notify the authorities about the quantity of mercury contained in the batteries, pay fees that are equivalent to the disposal costs of used batteries, and distribute the information provided within the framework of the regulations[47] (23 Swedish Kroner/kg for alkaline and mercury batteries, 13 Swedish Kr/kg for rechargeable nickel-cadmium batteries). All firms that do not properly collect and dispose of used batteries are open to prosecution. Regulations respecting nickel-cadmium secondary cells have been in place since April 1987.[86]

The Swedish company SAB Nife, which manufactures nickel-cadmium secondary cells, has an installation for recycling cadmium (Figure 19). SAB Nife received a government grant to develop a thermal method that recycles waste from the production of nickel-cadmium secondary cells. These installations are situated at the company's manufacturing plants in Oskarshamn. Cadmium and other materials from used batteries are recovered together with manufacturing wastes.

The plant has three sections: disassembly, chemical processing, and cadmium distillation. The plant operates a modified distillation method to recycle sealed cylindrical batteries and nickel-cadmium button batteries. The first stage in this process consists of collecting the batteries in barrels, then heating the barrels to 400-500°C. Once pyrolysis of the contents is complete, the temperature is raised to 900°C for the distillation process.[18]

The installation annually recycles over 1 000 tonnes of nickel-cadmium batteries to produce 150 tonnes of recovered cadmium (with 99.5% purity), 340 tonnes of nickel containing ferrous residues, 480 tonnes of ferrous residues, and 30 tonnes of plastic (Table 31).

6.2.7 Denmark

Government authorities, importers and retailers initiated a mercury battery recycling program in 1977.

The National Environmental Protection Agency organized a publicity program (using a publication about mercury) that urged consumers to return used batteries to collection boxes in retail shops. These boxes were designed by the Agency and distributed by the importers. Once full, they are returned

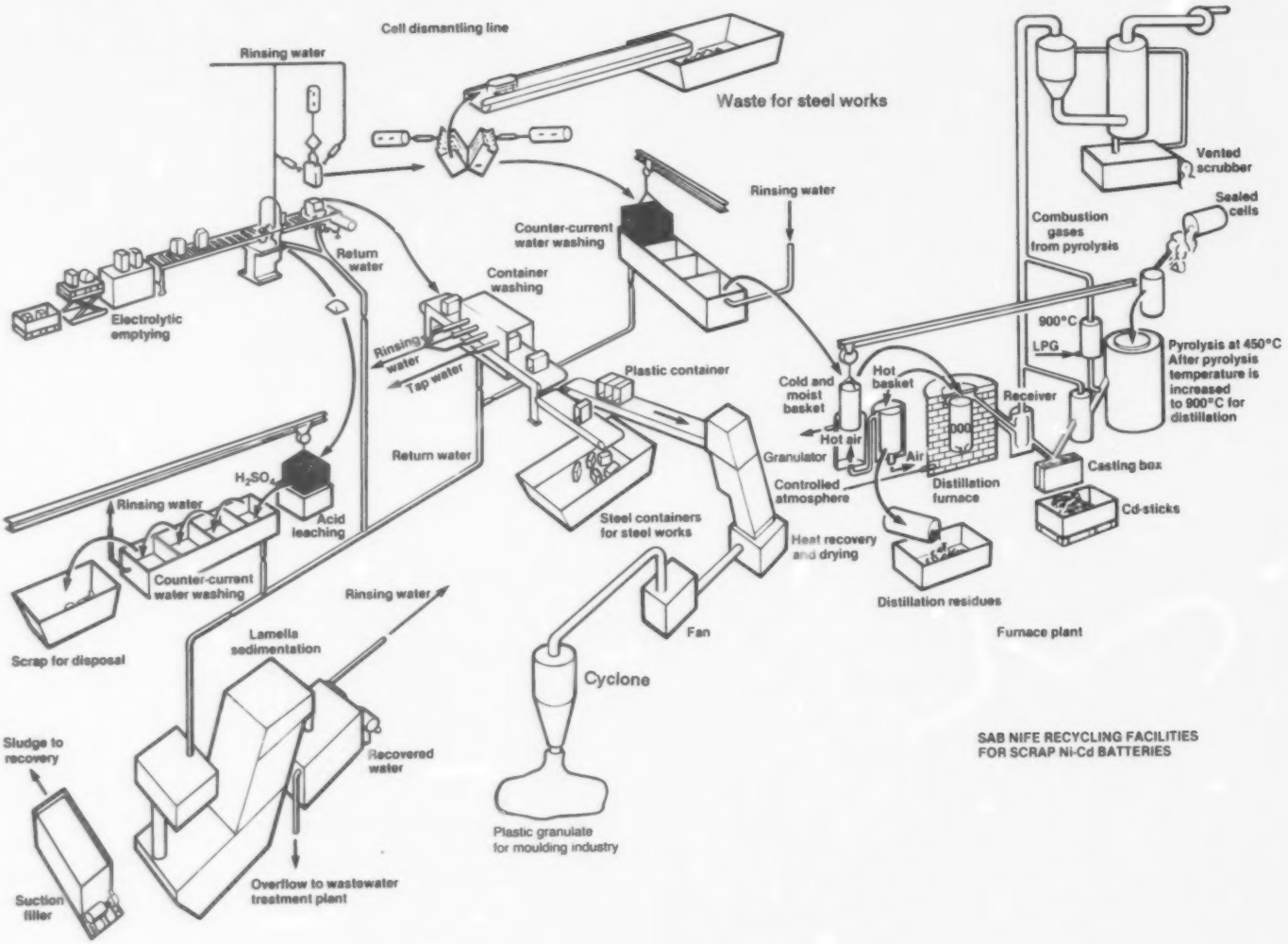


Figure 19 The Cadmium Recycling Operation at SAB NIFE [18]

Table 31 Capacity of Cadmium Recycling Plants

Plant	Recycling capacity (t/yr)	Production of Cd (t)
SAB Nife	1 000	150
SNAM	500	60

Source: 18

postpaid to the importers, who are responsible for the appropriate disposal (recycling or controlled disposal) of the collected batteries, depending upon their contents. Since January 1979, importers are required to produce a biannual report on the sales of mercury oxide batteries.[42]

In Denmark, the collection rate of mercury batteries is equivalent to that of Sweden; namely, 50% in 1982.[42] Since that year, however, the use of mercury oxide batteries has decreased considerably in Denmark. This is a result of the program carried out by battery importers and authorities, and aimed at the replacement of HgO batteries.

HgO batteries are collected in Denmark; however, there is no official collection program for used batteries.[87] Nevertheless, many specialized retailers, and a large supermarket chain have started their own programs for the collection of used batteries (button batteries and other kinds of used batteries). The unsorted, collected batteries are sent to an installation owned by the Kommunekemi A/S company, which specializes in processing toxic waste.[87] Batteries containing mercury are then placed in plastic barrels and exported for controlled disposal in salt mines.

Denmark was the first country to introduce legislation concerning sales, imports, and the disposal of primary and secondary batteries. The authorities' legislation will encourage the industry to reduce the mercury and cadmium contents of batteries, identify clearly those batteries with mercury and cadmium contents that exceed the recommended levels, and adequately dispose of collected batteries.[25] The reduction in the mercury content of batteries is being achieved gradually; however, the content must be 0.13% of the total weight by 1993.[37] No restrictions are applied to batteries containing less than 250 mg of cadmium. Batteries that contain more than this amount, and other products that contain cadmium must be labelled in accordance with provisions approved by the National Environmental Protection Agency.

6.2.8 Austria

In Austria, government authorities classify electric batteries as hazardous waste; therefore, they strongly encourage the battery industry to collect and recycle used batteries.[88] As a result, more than 60% of all types of batteries are recovered. The collected used batteries consist mostly (by weight) of carbon-zinc batteries, since their consumption represents about 70% of the battery market. Their share of the market is nevertheless being encroached on by alkaline batteries.[40]

Acting on a mandate from government authorities, the Austrian firm Voest-Alpine developed a method to recycle used batteries. Voest-Alpine operates an installation that can recycle over 1 000 t/yr of used batteries (button batteries and other kinds of used batteries). Plants with larger recycling capacities (2 500 t/yr and 5 000 t/yr) are being planned for Austria and other countries.[40] A study has revealed that the average heavy metal content of collected batteries, apart from mercury, is:

zinc: 10-30%;
manganese: 15-22%;
lead: 0.05-0.6%
cadmium: 0.8%;
copper: 0.1%.

These proportions represent batches of batteries that contain mostly carbon-zinc batteries (70%). According to the designers, the advantage of the Voest-Alpine method is that it can recycle all kinds of batteries in one location.

The Voest-Alpine process is illustrated in Figure 20. The first stage consists of mechanically sorting button and cylindrical batteries, which are then recycled separately. The primary and secondary materials are extracted during thermal and chemical processes.[40]

6.2.9 Other European Countries

Various European countries are experimenting with the collection of used batteries on a national or local scale. Due to lack of information on these countries, this section briefly describes used battery collection in the United Kingdom, Belgium, and Italy.

There are no national programs for the collection and recycling of used batteries in the United Kingdom (although there is a program for recycling manufacturing waste). The Department of the Environment has recently issued a Code of Practice recommending the use of zinc-air batteries for hearing aids. This program encouraged replacement of mercury oxide batteries and it had the effect of reducing by 50% the quantities of mercury associated with the use of these batteries.[42] The Department of Health and Welfare, in collaboration with an English firm, organized the collection of button batteries used in hearing aids. The collected batteries are subsequently sent to the Department, then exported for suitable recycling or disposal (in the past, they were sent to the Elwenn & Frankenbach Gmbh plant in Frankfurt).[89] In the United Kingdom, the Varta company collects used batteries from public sector organizations (about 20 t/yr), and covers the costs of final disposal in controlled sites.[18] In the United Kingdom, the Johnson Mathey and Engelhard companies have long recycled silver oxide batteries from various countries, including Canada.

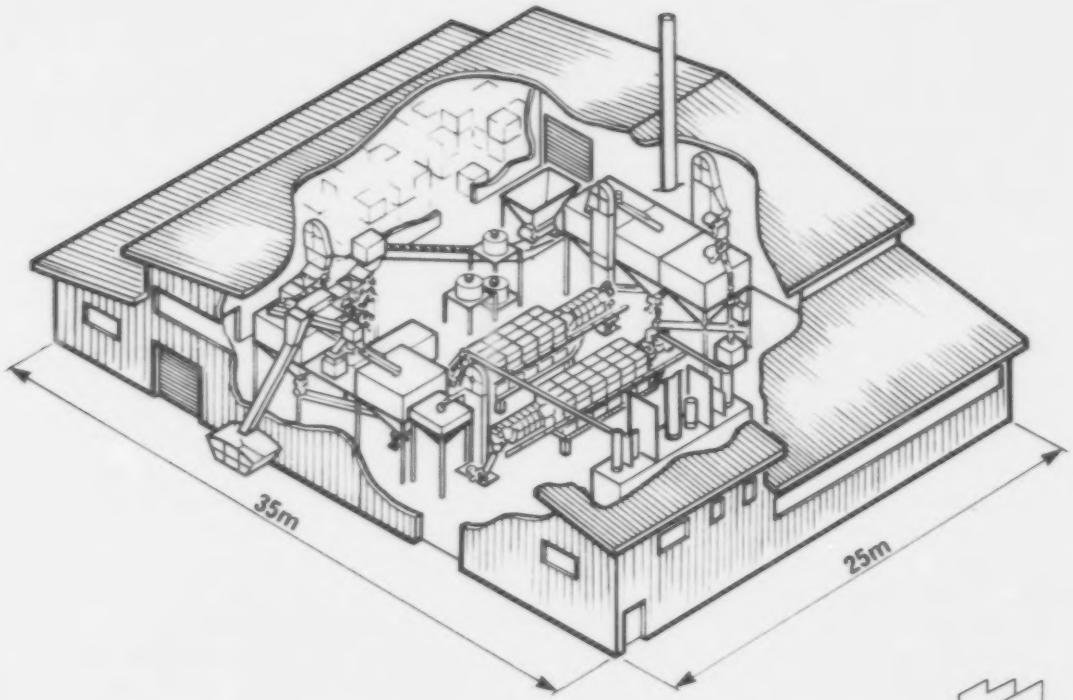
In Belgium, button batteries have been recovered since 1983 with the support of government authorities. Collection boxes have been placed in various retail shops, and the used batteries are generally collected by local environmental protection associations.[31]

Italian government authorities recently introduced legislation on waste management that classifies electric batteries as hazardous waste which must be separated from general household waste. However, only the municipal authorities of Reggio Emilia (a small municipality and province in northern Italy), have organized a system to collect used batteries. The consumption of batteries is about 48 t/yr for the town of Reggio Emilia, and about 151 t/yr for the whole province.[90] Alkaline and carbon-zinc batteries are recovered but not recycled, encased in concrete, and buried in controlled disposal sites.

6.2.10 Japan

In view of the small number of landfill sites available, the problem of batteries in household waste is particularly serious in Japan. Projections indicate that in 10 years, over 10 000 contaminated sites will be converted for other purposes. The increasing quantities of mercury in the soil near landfill sites has been attributed largely to dry batteries, and this contamination is a growing concern.[91] It is important to emphasize that half the national consumption of mercury in Japan is used for the manufacture of electric batteries.[27]

Programs for the collection of used batteries have been implemented to prevent squandering resources, and particularly to



VOEST-ALPINE
ENVIRONMENTAL
ENGINEERING

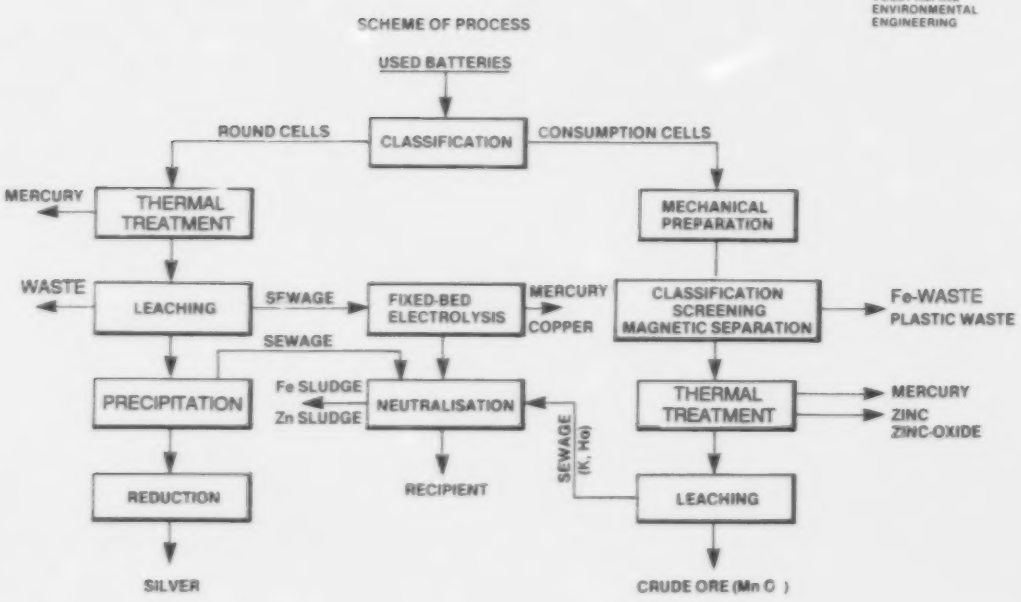


Figure 20 The Voest-Alpine Process[40]

meet the ever-growing public concern with mercury pollution.[54] Since 1984, the problem of used batteries has increasingly attracted public interest. There are two programs for the collection of used batteries in Japan. Cylindrical (alkaline) batteries are recovered by about 73% of Japanese municipalities; button batteries are collected by manufacturers with the cooperation of retailers. Under the supervision of government authorities, the manufacturing industry organized a program to collect mercury button batteries, and provided over 200 000 collection boxes to the retailers involved. In spite of the authorities' efforts, only 9% of cylindrical batteries are collected, compared with 27% of button batteries.[54]

Sorting at source, and the disposal of used dry batteries, are generally carried out in large population centres, towns, and municipalities. Municipal authorities generally support organizations that collect used batteries, by providing grants of financial aid.

Several municipalities have introduced regulations requiring that batteries be collected separately from household waste.[92] In fact, over 657 of the 3 200 municipal waste management authorities implemented programs to separate used batteries from household waste, in 1985.[93] About 70% of the municipalities provide support for these efforts, and over 111 000 retailers throughout the country collaborate by accepting all used batteries. The low rate of collection achieved by the retailers (about 15%) and local authorities that carry out separation at source (20%), is partially due to the lack of economic motivation.[92]

Most of the collected batteries are stored, and the authorities now face the problem of adequate disposal. Over 30 municipalities send their collected batteries to the only plant in the country that recycles used batteries.

Japanese battery manufacturers have taken preventive measures to reduce the mercury content of alkaline batteries. The mercury content has been cut back to 1/6 of the original content (1983 figures) since October 1987. This reduction is achieved by adding small quantities of lead, indium, or other rare metals to the zinc particles used for the anode.[27] Japanese manufacturers have also made a commitment to put limits on the production and use of mercury oxide batteries.[94]

In 1985, with the financial backing of the government, a non-profit organization, Clean Japan Center, built an experimental plant to recycle used dry batteries and fluorescent tubes containing mercury.[92]

Since 1984, all button batteries and some of the dry batteries collected are sent to the Itomuka Mercury Refining plant, an installation designed for mercury recycling. This plant, located in Hokkaido (the north of the country), has a daily recycling capacity of 20 tonnes of batteries, or 6 000 t/yr[94] (Table 32). The Nomura Kosan Co. operates

Table 32 Quantity of Metals Recovered Daily in the Hokkaido Plant in Japan

Metals	Quantity recovered	Purity of the product (% in weight)
Mercury	14-21 kg/day	70-98% Hg
Zinc and others	8-11 t/day	28-38% Zn
Ferrous residues	3-4 t/day	90-95% Fe

Source: 94

this facility. Recycling costs amount to almost $350/t of batteries; transportation costs can reach 50% of this sum. Due to high transportation costs, some towns cannot afford to send their used batteries to this installation. Dry batteries are sent to the plant where they are mixed with concrete and finally discarded or stored in wait of an economical recycling solution.[54]

The recycling method is illustrated in Figure 21. Special equipment sorts the batteries by size and shape, and removes the external casing of the batteries for the ferrous metal recovery.[92] Assuming a 70% rate of collection, some authors recommend the installation of five recycling plants in Japan (each with an annual capacity of 10 000 tonnes of batteries). A problem resides, though, in the choice of a site for each plant.[92,93]

The recycling method consists of a preliminary process that mechanically sorts the batteries into five categories, before dismantling the cylindrical batteries. The second stage is a thermal process that effectively extracts mercury by condensation. The mercury is then refined to a purity of 99.99% in weight. The third stage in the process is the recovery of ferrous and non-ferrous metals, mainly zinc. The recovery of manganese and other metals from the batteries will be carried out during a later phase which is currently under development.[94]

6.2.11 United States

Mercury is included in the list of hazardous atmospheric pollutants; the Environmental Protection Agency (EPA) has issued national emission standards for some industries that use mercury. However, there are no regulations for the sale and disposal of primary and secondary cells. By recognizing that municipalities face problems associated with the disposal of household waste, the EPA formed a Municipal Waste Task Force that will be responsible for a management strategy. This Task Force will focus on reducing and recovering waste, including the recovery of domestic batteries.[95]

According to a study on metal-bearing wastes, used mercury batteries are a second priority after spent pot linings of incinerators.

Some American states are becoming increasingly concerned with the presence of used batteries in household waste. They are responding to citizens that grow concerned with heavy metal emissions from municipal incinerators. The Recycling Branch of the New Jersey Environmental Protection Agency, for example, is studying the development of a recycling market for used batteries.[96]

For some time, an ad campaign launched by the Hearing Aid Journal has encouraged American hearing aid manufacturers to collect used batteries. According to a study, if the mercury batteries used by the military sector were also recovered, it would be possible to solve the problem.[97] Collecting the used mercury batteries of the military sector and implementing a vast program of public education would encourage the collection of used batteries in private firms, and the installation of local facilities for mercury recycling in the United States.

There are a few pilot projects in some American states for the collection of used batteries, but these have not been organized by federal authorities.[95] New Hampshire (NH) and Vermont (VT) operate a selective local collection of all used batteries. Since the spring of 1987, the NH-VT Solid Waste Project, a consortium of 26 municipalities in the two states, has collected used batteries (button, alkaline, carbon-zinc, and other batteries) in an effort to reduce the concentration of heavy metals in household waste. The success of the program has been ensured by the collaboration of 70 retailers in the region, where specially designed collection containers (identified with a logo) have been installed (Figure 22).[98] Consumers are strongly encouraged by retailers and

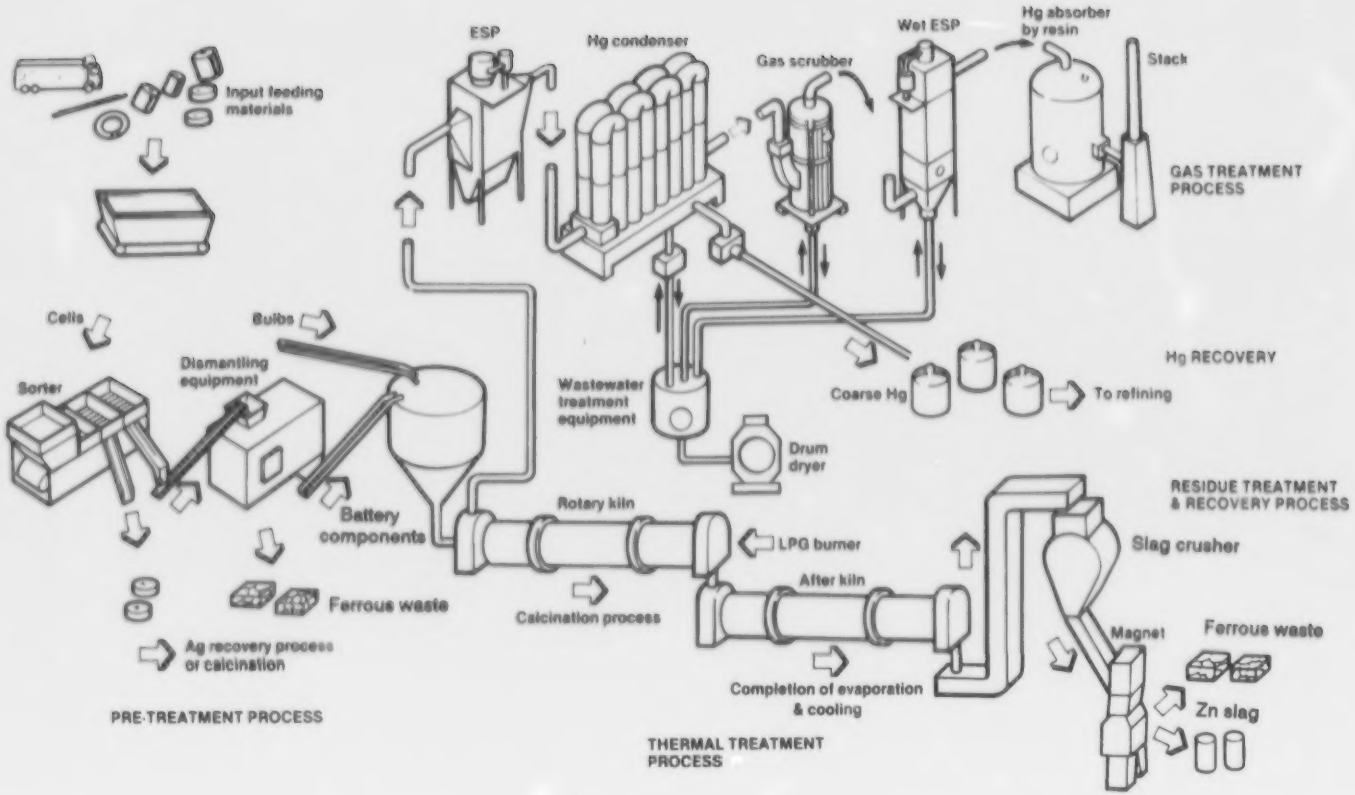


Figure 21 **Schematic of the Nomura Kosan Recovery Process** [94]

Household Batteries

WANTED:
HOUSEHOLD
BATTERIES

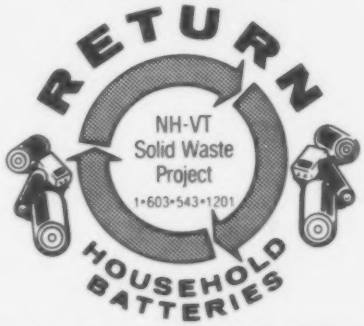
Recycling Makes Cents

Household batteries (also known as dry cells) power such items as:

* Flashlights
* Hearing Aids
* Tape Recorders
* Cameras
* Smoke Detectors
* Toys

Batteries contain heavy metals such as lead, mercury & cadmium. By returning your used batteries to a collection bucket in the store where you purchased it or to the collection container at the Recycling and Transfer Station, you can reduce the amount of heavy metals disposed of in the landfill or waste-to-energy facility.

Watch for this sign in participating stores and recycling facilities.



WATCH Tomorrow for Information on Plastic Recycling.
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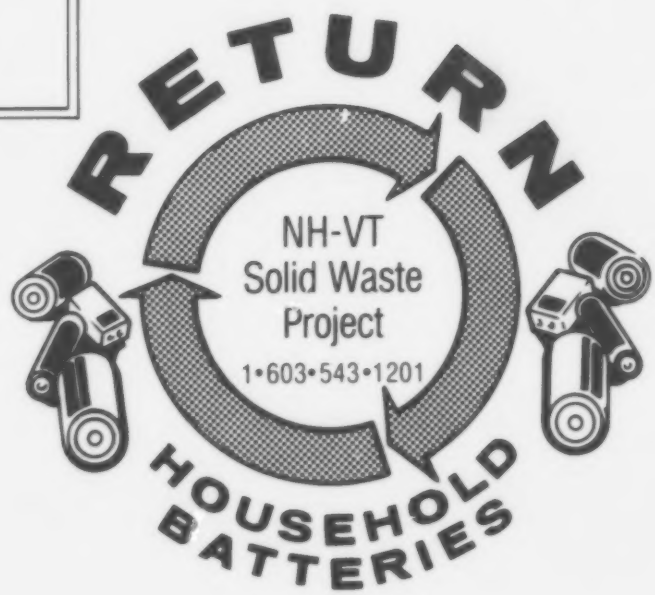

Figure 22 NH-VT Solid Waste Collection Project[4]

through publicity, to return used batteries. Some citizen organizations are responsible for collecting the containers and sorting the batteries. The recovered mercury and silver batteries are sent to the Mercury Refining Co. plant in Albany, New York, which specializes in recycling compounds containing mercury and silver. The company buys mercury batteries at a price of $0.20 US per pound, and offers $14 US per pound for silver oxide batteries. However, if the batches contain button batteries, the purchase price is reduced.[99]

An initiative by the NH-VT Solid Waste Project encouraged the Environmental Action Coalition (EAC), a non-profit organization that works with the Department of Sanitation in the City of New York, to develop its own program for the collection of mercury and silver button batteries. For some time, the EAC has coordinated an experimental program for sorting at source (newspaper, glass, plastic, aluminum); containers have been installed in various apartment buildings in the city. Since March 1988, button batteries, cylindrical batteries and other products have been added to the existing program. Additional containers will be installed in specialized city stores, and collected by the EAC. Collected button batteries (HgO and Ag_2O) are sent to the Mercury Refining Co. plant in Albany, New York, where they are recycled.[100] The EAC is presently interested in the Voest-Alpine method of recycling used batteries.

The Household Hazardous Waste Project of the State University of Missouri is considering a selective program to collect used batteries based on the system developed by the NH-VT Solid Waste Project.[101]

Section 7

Quantification of the Problem in Canada

7.1 Quantity of Mercury Contained in Used Batteries

In a market as competitive as the battery market, it is difficult to obtain statistics from the manufacturers. Sufficient data was obtained, though, that allowed the authors to carry out mathematical operations that reflect the situation with enough precision for the needs of this study. Recall that the Canadian battery market increased by 62% between 1982 and 1986; sale figures also increased, from 136 to 221 million dollars. During this period, the increase in the number of batteries sold was lower: 29.2%. According to this study's estimates, about 130 million batteries were sold in Canada in 1982, and 170 million batteries were sold in 1986. This gain illustrates the increase in the sales of top-of-the-line batteries, which can be attributed largely to the growing popularity of alkaline batteries. Battery sale figures in Canada are distributed according to Tables 33 and 34.

The market for domestic batteries also changed in terms of the formats used. The popularity of the "AA" format has increased significantly, as shown in Table 35.

Since the quantities of mercury contained in the batteries are expressed as a weight

Table 33 Distribution of Canadian Battery Sales, 1982-1986

Type of battery	1982 (millions of $)	1986 (millions of $)
Alkaline	87.0	132
Carbon-zinc (high performance)	29.9	24
Carbon-zinc (ordinary)	10.9	31
Rechargeable	4.1	11
Others	4.1	23
Total	136.0	221

Source: 11

Table 34 Number of (Alkaline and Carbon-Zinc) Batteries Sold in Canada, 1982-1986

Type of battery	1982 (millions of units)	1986 (millions of units)
Alkaline	76.6	103.8
Carbon-zinc	51.2	55.4

Source: 11

Table 35 Battery Formats Used in Canada (Alkaline and Carbon-Zinc)

	1982 (millions of batteries)		1986 (millions of batteries)	
Format	alkaline	carbon-Zn	alkaline	carbon-Zn
AAA	6		5.2	?
AA	27	13	56.0	22.7
C	17.5	15	15.6	11.6
D	17	16	16.6	13.3
9 V	9	6.5	10.4	6.6
Flashlight	-	1	?	1
Total	76.5	51.5	103.8	55.2
Increase (%)	35.7	7.2		
Overall total	128	159		

Source: 11

percentage, it is necessary to measure or estimate the weight of various types of batteries. The results are Table 36.

According to most of the studies consulted, the concentration of mercury (by weight) of the various types of batteries is:

carbon-zinc: 0.01%
alkaline: 1.0%
Ag_2O: 1.0%
zinc-air: 1.0%
HgO: ~30 %
lithium: 0 %

Conforming to the EEC directive (section 6.1), the mercury content of batteries in Europe should be reduced by 85% by 1990; Japan is carrying out similar reductions.

According to a large North American battery manufacturer, the present concentration of mercury in alkaline batteries is at most 0.8%, and less than 0.05% in the case of carbon-zinc batteries.[52] Mercury concentrations of 0.8% and 0.01% were considered respectively for alkaline and carbon-zinc batteries. The compilation of mercury quantities is shown in Table 37.

It was not possible to obtain valid data from manufacturers concerning other types of batteries. Instead, statistical averages of European, Scandinavian and Japanese consumption were used, in view of the similar life styles. The results are Table 38.

The total quantity of mercury associated with the disposal of used batteries in Canada was estimated at about 50 t/yr (1982: 45.7 t/yr, 1986: 48.3 t/yr); this estimation includes primary cells.

7.2 Problems Related to Cadmium from the Disposal of Rechargeable Batteries and Industrial Nickel-Cadmium Rechargeable Batteries

The use of rechargeable nickel-cadmium batteries is growing rapidly. At the end of their useful life (about five years), they are

Table 36 Battery Weights

Format of batteries	Carbon-zinc (g)	Alkaline (g)
AAA	7.5	10
AA	16	22
C	50	66
D	100	132
9 V	38	46

Source: Eutrotech Inc.

Table 37 Mercury Content of Used Batteries in Canada (Carbon-Zinc and Alkaline Batteries Only), 1982-1986

	1982		1986	
Type of battery (% Hg)	Total weight (t/yr)	Hg (t/yr)	Total weight (t/yr)	Hg (t/yr)
Alkaline (0.8%)	4 467	35.7	4 983	39.9
Carbon-zinc (0.01%)	4 305	0.4	4 024	0.4
Total Hg		36.1		40.3

Source: 52

Table 38 Mercury Content of Batteries (Mercury Oxide, Silver Oxide, Zinc-Air)

	1982		1986	
Type of battery	Total weight (t/yr)	Hg (t/yr)	Total weight (t/yr)	Hg (t/yr)
Mercury oxide	31	9.3	25	7.6
Others Ag_2O Zinc-air	37	0.3	45	0.4
Total		9.6		8.0

Source: Eutrotech Inc.

discarded like all types of domestic batteries. Several countries are considering measures to collect them; and some, like Switzerland and the Netherlands (southern provinces) have already established collection programs.

Industrial nickel-cadmium secondary cells have been in use for a long time; due to the heavy weight of their electrodes, their recovery offers potential profits. For example, the nickel cathode has a higher value than that of the cadmium anode.

In Europe and Scandinavia, the recovery of industrial nickel-cadmium secondary cells is proceeding relatively well. Used secondary cells are sent to one of two cadmium recovery plants presently in operation (section 6). In view of the existing low value of cadmium, some small recovery firms are stockpiling the cadmium anode and treating only the nickel cathode, while waiting for an increase in the price of cadmium.

Studies carried out in Quebec and Ontario did not reveal the final destination of used industrial nickel-cadmium secondary cells in these provinces. Normally, the users send them to the retailers, which apparently forward them to Ontario. However, as far as the authors of this study know, there are no cadmium recycling plants in Canada.

Taking into account the value of the nickel cathode, it is highly probable that it is recycled; however, what happens to the cadmium anode? The authors of this study recommend further investigations.

7.3 A Comparison Between the Situation in Canada and Those in Other Countries

It was previously mentioned that Canadian consumption of mercury, lithium, silver, and zinc-air batteries was estimated on the basis of foreign consumption averages. A more thorough evaluation was carried out, however, for the Canadian consumption of alkaline and carbon-zinc batteries.

In comparison with other countries, with the exception of the United States, the situation in Canada is markedly different, due to the massive use of alkaline batteries. This consumption directly affects the quantity of mercury generated, since alkaline batteries are a major source. Table 39 compares the situation in Canada to those in other countries.

7.4 A Comparison Between the Amounts of Mercury Derived from Used Batteries and the Amounts of Mercury Derived from Other Man-Made Sources

To determine the relative amounts of mercury derived from used batteries, it is important to discuss sources of mercury related to other human activities. Information on these other sources of mercury was obtained from various documents and the figures are only estimates. For the purposes of this study, if the mercury contained in various products was not recycled, it was counted as waste dumped into the environment. The accumulation of this type of waste may be more or less rapid (or damaging), depending upon the type of disposal method (sections 5.2.1 and 5.2.2).

Table 40 shows an estimate of mercury emissions in Canada produced by human activities.

Considering the figures shown in Table 40, it is possible to reach several conclusions in terms of future trends.

- In a few years, mercury thermometers will be rarely used; they will be increasingly replaced by digital thermometers;

- Dental amalgams are being gradually replaced by new dental preparations that do not contain mercury;

- The reduction in mercury emissions by the caustic soda industry is quite remarkable. In 1970, this source represented 32% of the total emissions of mercury in Canada. Today, it only

Table 39 Used Batteries and Mercury: The Situation in Canada (1982 and 1986) and in Other Countries (1982)

Country	Japan	Germany	Switzerland	France	The Netherlands	EEC	Sweden	Denmark	Canada 1982	Canada 1986
Population (Millions)	120	61	6.4	55	14.4	271	8.3	5.1	25	25.4
Carbon-Zinc Batteries										
t/yr	37 900	13 800	3 500	22 000[1]	3 000	62 000	-	-	4 305	4 024
t/yr Hg	3.79	1.4	0.3	2.2	0.3	6.2	-	-	0.4	0.4
Alcaline Batteries										
t/yr	7 050	4 600	1 100	10 000[1]	700	17 330	365	233	4 467	4 983
t/yr Hg	70.5	35	8	100	7	173.3	3.6	2.3	35.7	39.9
HgO Batteries										
t/yr	172	75	13	20	12.3	218	12.8	7	31	25
t/yr Hg	51.5	25	4	7.8	3.7	65.4	3.8	2	9.3	7.6
Other Batteries (zinc-air, Ag_2O, lithium)										
t/yr	221	37	13	24	-	280	3[2]	13.5	37	45
t/yr Hg	2.21	0.4	0.13	0.24	-	2.8	0.03[2]	0.13	0.3	0.4
Total										
t/yr	45 343	18 512	4 626	32 044	partial 3 712	79 828	very	very	8 840	9 077
t/yr Hg	128	61.8	12.4	110.2	11	247.7	partial	partial	45.7	48.3
g/person/yr	378	303	723	583	258	294			354	357
g Hg/person/yr	1.07	1.01	1.94	2.0	0.76	0.91	-	-	1.82	1.90

[1] 1987
[2] uncertain

Source: Eutrotech Inc.

Table 40 Man-Made Mercury Emissions in Canada

	t Hg	%
Used batteries (1988)	50	35
Industrial and control instruments	24	16.8
Paint	19	13.3
Mining industries	16.2	11.3
zinc 9.8 t		
copper 6.0 t		
lead 0.4 t		
Dental amalgams	10	7
Fossil fuels	9	6.3
Fluorescent and mercury lamps	4.5	3.1
Thermometers	4	2.8
Caustic soda industry	2.7	1.9
Agriculture	2	1.4
Pharmacy	1.5	1
Total	142.9	

Note: 1982 data, except for batteries

Source: Eutrotech Inc.

amounts to about 2%. The few plants equipped with mercury cells will cease to operate in the near future;

- Like other countries, Canada should forbid the use of mercury as a fungicide in paints;
- The collection and recycling of industrial electrical instruments containing mercury should be considered; and
- The eventual installation of equipment to reduce acid atmospheric emissions by the mining industry should reduce mercury emissions. In Scandinavia, the mining industry is recovering the mercury contained in gas emissions; the mercury recovered meets the needs of the country for this metal.

7.5 Canadian Reactions to the Problem of Used Batteries

The installation of an incinerator in Burnaby gave rise to a very animated debate that was extensively reported in the local press. People in the Vancouver region were concerned about the emission produced by the new incinerator; the question of the mercury contained in used batteries was raised several times. However, the new installation seems better equipped to purify gas emissions than most incinerators in the country. In fact, it is equipped with a gas scrubber. People were also concerned with the incinerator ashes, which generally contain such heavy metals as lead, cadmium, and mercury. The Greater Vancouver Regional District is considering the problem, and will evaluate whether it will be necessary to collect used batteries separately.

Most waste produced by the Toronto region is incinerated. A local program for the collection of all used batteries was implemented in November 1987. An advertising brochure was distributed with electricity bills to encourage participation. People were asked to deposit their used batteries in one of 17 containers located near glass and aluminum recovery bins.

It is too early to evaluate the response of the citizens. The collected batteries are presently being stored while waiting for the construction of a recycling facility by HEVMET Recovery Limited, in Port Colborne, Ontario. This company is planning to install a recycling plant based on the Austrian model (Voest-Alpine); this will make it possible to process all kinds of batteries.[100]

As far as the authors of this study know, the mercury recycling plant closest to Canada is located in Albany, New York.

Section 8

Recommendations

The information collected during this study revealed that a program for the collection of used mercury (HgO) batteries alone would not be effective in significantly reducing the mercury emissions from used batteries. There are two reasons: of a total of 48 tonnes of mercury released per year, only seven tonnes can be attributed to mercury batteries and secondly, the use of this type of battery is decreasing. In fact, a few years ago, Japanese industry agreed to stop developing new applications for mercury batteries. Furthermore, today there are other types of batteries that can replace mercury batteries successfully. For example, zinc-air batteries can replace mercury batteries in most hearing aids, which have been until recently the main application of mercury batteries.

A program for the collection of used batteries should consequently include alkaline batteries; they alone account for over 40 t/yr of the mercury emissions in Canada. Clearly, a national program for the collection of used batteries will face many problems related to the sorting, storage, final recycling, and particularly the high cost of transporting these batteries (in view of the distances between urban centres). Furthermore, the collection rate for used batteries is generally low, especially in terms of cylindrical (alkaline) batteries, even in countries where the public has been aware of the problem for many years. According to tests that are now being carried out in some European countries, the major problems associated with used battery collection programs (alkaline and other types of batteries) are economic. In fact, when cylindrical batteries are included in the collection program, recycling has rarely proven economically feasible.

Despite the large quantity of mercury in used batteries, this study cannot recommend, at this time, the implementation of a program for the collection of used batteries. The authors suggest that it would be more effective and economical to consider a reduction in the quantities of mercury in batteries.

In Canada, mercury emissions attributable to used batteries could be reduced by 80%, by implementing the following recommendations:

- Replacing mercury oxide batteries by batteries containing little or no mercury, through the adoption of motivational or legislative measures. For example, zinc-air batteries can replace mercury batteries in hearing aids; this replacement is technically and economically feasible. Thus, it would be important to sensitize both the users and manufacturers of hearing aids, through information programs.

- Adopting legislative measures similar to those of the EEC, which aim to progressively reduce by 85% the concentration of mercury in alkaline batteries by 1990; and

- Implementing measures requiring that all municipal incinerators be henceforth equipped with wet gas scrubbers. In effect, the mercury emitted in the form of gas during the combustion of household waste easily bypasses current fly-ash removal systems. The problem of mercury emissions from incinerators adds to other factors that favour cleaning gas emissions more thoroughly. The authors of this study feel that gas scrubbing equipment is absolutely necessary for all municipal incinerators.

In view of the increasing popularity and high cadmium content (about 15%) of rechargeable nickel-cadmium batteries, this study recommends that further research be carried out on the problems related to the disposal of these batteries.

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Appendix

List of Organizations

ANRED
National Agency for the Recovery and Disposal of Wastes
2, Square La Fayette
B.P. 406
49004 Angers Cedex
France
M. Pascal Baranger
M. Daniel Beguin

Duclos Environnement
86, route Nationale
13240 Septème les Vallons
France

SNAM
Société nationale d'affinage des métaux
Rue de la Garenne
Z.I. de Tharabie
St-Quentin-Favallier
38290 La Verpillière France
M. Jacques David

SETACI
6, rue Métropole
73000 Chambery France
M. M.L. Durand

Office Fédéral de la Protection de l'Environnement
(Bundesamt fur Umweltschutz) BUS
Section déchets & technologies de traitement
Hallwaylstrasse 4
CH 3003 Berne Switzerland
M. Mathias Tellenbach

Action pour la Propreté en Suisse
Kernstr, 31
CH 8026 Zurich Switzerland
Mme Miriam Bieri

Institut Fédéral pour l'Aménagement, l'Épuration et la Protection des Eaux
(EAWAG)
(Swiss Federal Institute of Technology)
Section des déchets solides
Uberlandstrasse 133
CH 8600 Dubendorf Switzerland
Prof. Baccini

Leclanché SA
48, Av. de Grandson
CH-1401 Yverdon Switzerland
M. Rüetschi, Technical Director

Fédération des Coopératives Migros
Migros-Genossenschafts-bund
Marketing Department
Limmatstrasse 152
CH 8005 Zurich Switzerland
M. R. Biber/M. Gugelman

Amt Fur Gewasserschutz
Lumatrastrasse
Walcheplatz
CH 8001 Zurich Switzerland
M. Jurg Zaugg, Engineer

AFIF, ETH-Zentrum (ETZ)
Gloriastrasse 35
CH-8092 Zurich Switzerland
M. P. Bohac

EIC S.A.
Muhlebachstr. 54
CH-8008 Zurich Switzerland
M. A. Vital

Orfa-Umwelttechnik AG
Pfingstweidstr. 101
Postfach 266
CH-8031 Zurich Switzerland
M. H. Meier

EUROPILE
Association of Electric Battery Manufacturers
General Auditing Company Ltd.

Waisenhausplatz 25
P.O. Box 2613
CH-3001 Berne Switzerland
M. H.G. Herzberg

Recytec S.A.
Résidence de la Côte 70
App. 41
CH-1110 Morges Switzerland
M. Fiola

Umweltbundesampt
Bismark Platz 01
D-1000 Berlin 3 Germany
M. W. Genest

VROM
Solid Waste Division
DGMH-Bldg
M. V.D. Stamstraat 2,
P.O. Box 450
2260 MB Leidschendam The Netherlands
M. Rolf Bohmann/M. Hans Erasmus

FME/NEFIBAT
Bredewaterzo
2715 Ca Zoetermeer The Netherlands
M.M.C. Meiyer

Battrex Zegwaard-Delft B.V.
Schieweg 60
P.O. Box 131
2600 AC Delft The Netherlands
M. N. Struijk

Leto Recycling B.V.
Beddrijvenpark N.W. Twente 243
7612 AC Aadorp The Netherlands
M. A.J. Schutman

TNO
P.O. Box 217
Schoemakerstraat 97
2600 AE Delft The Netherlands
M.D. Schmal, Dept. of Environmental Technology

Confédération Belge de la Récupération
(COBEREC)
Place du Samedi, 13 B.L. 5/6
1000, Bruxelles Belgium
M. Étienne Cochaux

UK Department of the Environment
Noise, Nuisance & Waste Division
Romney House 43
Marsham Street, London SW1 3PY
Room A2/22, United Kingdom
Mme A.H. Wood

Heavy Metals Secre.
CEP. Consultants Ltd
26 Albany Street
Edinburgh EH1 3QH United Kingdom

National Environment
Protection Board
Statens Naturuardsverk
Technical Dpt
Waste Management & Recycling
Box 1302
C.P. S-17125 Solna, Sweden
M. Anders Kjallman

Miljoestyrelsen (Ministry of the Environment)
Strandgrade 29
D.K. 1401
Copenhagen K Denmark
Mme Charlotte Christenson

Voest-Alpine Co.
P.O.B. 2
4010 Linz Austria

European Economic Community
(COMEUR)
200, rue de la Loi
B-1049 Bruxelles Belgium
M. J.M. Junger

Bureau International de la Récupération
13, Place du Samedi Bte 4
1000, Bruxelles Belgium
M. Francis Veys

OECD
Environment Directorate Division
2, rue André-Pascal
75775 Paris Cedex France
M. H. Yackovich

National Institute for Environmental Studies
Environmental Information Division
Yatabe-machi, Tsukuba
Ibaraki, 305 Japan
M. Suckehiro Gotoh, Director

Nomura Kosan Co. Ltd
Sankei Building, Annex,
7-02 Ohte Machi
1-Chome, Choyoda-ku
Tokyo 1[illegible]0 Japan
M. Kum[illegible] Koike, Director

Environment Agency
International Affairs Division
1-2-2 Kasumigaseki
Chiyoda-ku
Tokyo Japan
M. Kuniko Sato

Japan Battery & Appliance
Industries Association
No. 9 Mori Bldg
2-2 Atago
1-chome, Minato-ku
Tokyo 105 Japan
M. Masao Shinohara

Clean Japan Center
8 No. 2 Akiyama Bldg., 3-6-1
Toranomon, Minato-ku
Tokyo 105 Japan

Waste Management Division
Environmental Sanitation Department
Environmental Health Bureau
Ministry of Health and Welfare
1-2-2, Kasumigaseki,
Chiyoda-ku, Tokyo 100 Japan

New Jersey Environmental Protection Agency
CN 414, 802 Labor and Industry Bldg.
Trenton NJ 08625 U.S.A.
M. Michael F. de Bonis, Director
Mme Athena Sarafides, Dept. of
Environmental Protection

Environmental Action Coalition
625 Broadway
2nd floor
New York, N.Y. U.S.A.
M. David Hurd

Southwest Missouri State University
901 South National Avenue - Box 87
Springfield, Missouri U.S.A.
Mme Mary Steinwachs

Mercury Refining Ltd
790 Watervliet-Shaker Road
Latham, N.Y. 12110 U.S.A.
M. Leo Cohen

New Jersey & New Hampshire
Solid Waste Division
Room 336, Moody Building
Claremont, New-Hampshire 03743
U.S.A.
Mme Connie Leach

Toronto Recycling Action
Committee (TRAC)
Canada
M. Russel Nicholson

Greater Vancouver Regional District
4340 Kingsway, Engineering floor
Burnaby, B.C. V5H 4G8 Canada

Hevmett Recycling Ltd.
Port Colborne (Ontario)
Canada
M. Gary Mann

Moli Energy
3958 Myrtle
St-Barnaby, B.C. Canada
M. Herb Wang

Canadian Battery
Manufacturers' Association
1 Yonge St., Suite 1400
Toronto (Ontario) Canada
M. Alex C. Dick